PB88-113477

# Compendium of Costs of Remedial Technologies at Hazardous Waste Sites

Environmental Law Inst., Washington, DC

Prepared for

Environmental Protection Agency, Cincinnati, OH

Oct 87

U.S. Department of Commerce
National Technical Information Service
NTIS

PB88-113477

EPA/600/2-87/087
October 1987

# COMPENDIUM OF COSTS OF REMEDIAL TECHNOLOGIES AT HAZARDOUS WASTE SITES

by

Edward C. Yang, Dirk Bauma, Linda Schwartz, and James D. Werner
Environmental Law Institute
Washington, DC 20036

EPA Contract 68-03-3113

EPA Project Officer
Douglas Ammon

OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE
OFFICE OF EMERGENCY AND REMEDIAL RESPONSE
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, DC 20460

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

1. REPORT NO.
EPA/600/2-87/087

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Compendium of Costs of Remedial Technologies at Hazardous Waste Sites

5. REPORT DATE
October 1987

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Edward C. Yang, Dirk Bauma, Linda Schwartz and James D. Werner

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Environmental Law Institute
1616 P Street, NW
Washington, DC 20036

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-03-3113

12. SPONSORING AGENCY NAME AND ADDRESS
Hazardous Waste Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final, 1/85 - 9/86

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES
Project Officer: Douglas Ammon 513/569-7876

16. ABSTRACT

Accurate estimates of hazardous waste site remedial responses are important in order to: (1) budget the Superfund Response Fund, (2) estimate costs at specific sites, (3) cost-effectively select remedial actions, and (4) effectively negotiate with private response parties for private action or cost recovery. Unfortunately, standard engineering costing methodologies have been relatively inaccurate in estimating actual response costs. This is primarily due to the uniqueness of the site problems and the uncertainties in eventual effectiveness of the responses. The purpose of this document is to record and analyze the actual expenses incurred during remedial responses for seven major types of engineering technologies. The costs documented here are the "bottomline" numbers showing the ultimate cost of the responses. The data supporting this compendium is derived from a series of 31 case studies of actual hazardous waste remedial responses. This report also investigates the divergence between actual remedial costs and estimates from existing engineering cost methodologies. In addition, the compendium lists the major factors that cause the costs' movements. Because of the scope of the report coverage and the small sample size the data provided here to be viewed as "bench marks" for the estimation of future response costs. Users are urged to examine the specific site conditions underlying the reported costs by consulting the case studies from which these estimates are derived.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| | | |

18. DISTRIBUTION STATEMENT
Release to public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
205

22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

## NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# ABSTRACT

Accurate estimates of hazardous waste site remedial responses are important in order to: (1) budget the Superfund Response Fund, (2) estimate costs at specific sites, (3) cost-effectively select remedial actions, and (4) effectively negotiate with private response parties for private action or cost recovery. Unfortunately, standard engineering costing methodologies have been relatively inaccurate in estimating actual response costs. This is primarily due to the uniqueness of the site problems and the uncertainties in eventual effectiveness of the responses.

The purpose of this document is to record and analyze the actual expenses incurred during remedial responses for seven major types of engineering technologies. The costs documented here are the "bottomline" numbers showing the ultimate cost of the responses. The data supporting this compendium is derived from a series of 31 case studies of actual hazardous waste remedial responses. This report also investigates the divergence between actual remedial costs and estimates from existing engineering cost methodologies. In addition, the compendium lists the major factors that cause the costs' movements. Because of the scope of the report coverage and the small sample size the data provided here be viewed as "bench marks" for the estimation of future response costs. Users are urged to examine the specific site conditions underlying the reported costs by consulting the case studies from which these estimates are derived.

# CONTENTS

Page

NOTICE . . . . . . . . . . ii

ABSTRACT . . . . . . . . . . iii

TABLE OF CONTENTS . . . . . . . . . . iv

ACKNOWLEDGEMENTS . . . . . . . . . . vi

1.0 INTRODUCTION . . . . . . . . . . 1

**2.0 Surface Water Controls**

2.1 Surface Sealing . . . . . . . . . . 9

2.2 Grading . . . . . . . . . . 19

2.3 Drainage Ditches . . . . . . . . . . 23

2.4 Revegetation . . . . . . . . . . 27

**3.0 Groundwater and Leachate Controls**

3.1 Slurry Wall . . . . . . . . . . 33

3.2 Grout Curtain (Aspemix) . . . . . . . . . . 44

3.3 Sheet Piling . . . . . . . . . . 52

3.4 Grout Bottom Sealing . . . . . . . . . . 56

3.5 Permeable Treatment Beds . . . . . . . . . . 59

3.6 Well Point System . . . . . . . . . . 64

3.7 Deep Well System . . . . . . . . . . 67

3.8 Extraction/Injection Well System . . . . . . . . . . 71

3.9 Extraction Wells/Seepage Basins . . . . . . . . . . 74

3.10 Subsurface Drain . . . . . . . . . . 79

Contents (continued)

Page

**4.0 Aqueous and Solids Treatment**

4.1 Activated Sludge .......... 88
4.2 Anaerobic, Aerobic & Facultative Lagoons .......... 93
4.3 Rotating Biological Contactors .......... 99
4.4 Air Stripping .......... 103
4.5 Carbon Treatment .......... 119
4.6 Oil/Water Separator .......... 116

**5.0 Gas Migration Control**

5.1 Pipe Vents .......... 122
5.2 Trench Vents .......... 125
5.3 Gas Barriers .......... 129
5.4 Carbon Adsorption .......... 133

**6.0 Material Removal**

6.1 Excavation/Removal, Transportation and Disposal .......... 139
6.2 Hydraulic Dredging .......... 163
6.3 Mechanical Dredging .......... 168
6.4 Drum Handling .......... 172

**7.0 Water & Sewer Line Rehabilitation**

7.1 Sewer Line Replacement .......... 178
7.2 Sewer Line Repair .......... 181
7.3 Water Line Repair .......... 185
7.4 Water Main Replacement .......... 188

**8.0 Alternative Water Supplies**

8.1 New Water Supply Wells .......... 191
8.2 Water Distribution System .......... 194

**9.0 REFERENCES** .......... 197

# ACKNOWLEDGEMENTS

The Environmental Law Institute (ELI) prepared this report under a subcontract with SAIC of McLean, Virginia for the US EPA's Office of Research and Development, Hazardous Waste Engineering Research Laboratory and the Office of Solid Waste and Emergency Response, Office of Emergency and Remedial Response. This report was prepared by Dr. Edward C. Yang, Director of ELI's Resources Program, Dirk Bauma, Linda Schwartz and James D. Werner. Mrs. Nurhan Giampaolo of ELI and Ms. Diane Simmons of JRB Associates provided the administrative support for the project. The report was prepared under the direction of EPA Task Managers, Bruce Clemens (Office of Emergency and Remedial Response, Policy Analysis Staff - - James Lounsbury, Director) and Douglas Ammon (Hazardous Waste Engineering Research Laboratory, Land Pollution Control Division - - Ronald Hill, Director).

The project team greatly appreciates the overall guidance of the JRB Task Manager Claudia Furman and S. Robert Cochran, and the EPA Task Managers for their assistance and support.

## SECTION 1

# 1.0 INTRODUCTION

## 1.1 OVERVIEW

Response cost information is critical to several aspects of implementation of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), known as Superfund. These aspects include:

- Selecting cost-effective response alternatives
- Documenting reasonable costs for cost recovery
- Budgeting for fund balancing

The purpose of this Cost Compendium is to summarize existing cost information for these uses. Actual expenditures and estimated costs are both given to assemble data from all available sources into one data base. The immediate use of this centralized source of cost information is to provide consistency in various site-specific costing tasks such as: remedial alternative costing as required in the Feasibility Study Guidance Document (FSGD), and budgeting for immediate and planned removals. This compendium should be viewed as the first installment of an ongoing data base, which will be updated periodically as more cost information becomes available from completed Superfund responses. Cost data in this compendium are organized according to related technologies, such as "Ground-Water Controls" (see Table of Contents). The costs given are for technologies that have been most commonly used at uncontrolled hazardous waste sites, although some rarely used technologies are given because estimates are frequently cited. Commonly used technologies may have been excluded because of the paucity of data. Typically, however, the number of estimates and the depth of background information are often proportional to the frequency of use of the technology. In addition to the organization of cost data according to technologies, several other features of this cost compendium merits highlighting.

## 1.2 ACTUAL EXPENDITURES VERSUS ESTIMATES

Most available cost information is from engineering estimates. Few such estimates have been field tested, however. Preliminary comparison of these estimates with actual expenditures has shown significant differences in many cases (ELI/JRB, 1983). Since merging these two types of data would be misleading to the reader, this compendium separates, ex ante, engineering estimates from actually observed expenditures. Although actual expenditure data, which has been "ground truthed", are generally more reliable than estimated cost data, estimates are useful because they broaden the range of site characteristics and technical circumstances for which costs are available. The factors that were included in deriving the cost estimates may reflect a situation that more closely parallels the intended use of the cost data than any of the situations for which actual expenditure data are available.

## 1.3 FOCUS ON UNIT-COST

Data are given in a unit-cost form, in terms of dollars per unit operation, such as cost per square foot of slurry wall, or cost per gallon of treated water. Since the units used are important, consideration was given to the selection to ensure that they were useful and/or standardized throughout the industry. English measure only is used for simplicity. These unit costs typically include all related costs such as material, labor, and equipment and other capital costs. Operation and labor costs are given when they are applicable and available.

## 1.4 INCLUSION OF SUMMARY AND RAW DATA

This compendium organizes cost data into two levels: (1) summary data, and (2) raw data. The first level gives summary data such as range, and when possible, mean and standard error (see Table 1). This summation of the raw data should be used only for very general cost screening and budgeting, since the wide ranges of the data presented, and the lack of background explanation on this level render it unsuitable for more specific costing purposes. Such specific cost estimation should use raw data, on the second level, which provides more detail on the data compilation. This detail can be used for matching to the circumstances at the site for which it is to be used. The user should compare the site circumstances to the factors given in the raw data to estimate the effect of these factors on the estimated cost.

## TABLE 1

## RANGE OF UNIT COSTS ASSOCIATED WITH REMEDIAL TECHNOLOGIES [1]

| Technology | | Range of Unit Costs[2] | |
|---|---|---|---|
| | | **Expenditures** | **Estimates** |
| **4.0** | **SURFACE CONTROLS** | | |
| | Surface Sealing | $0.92 to $15.84/yd$^2$ | $1.32 to $16.88/yd$^2$ |
| | Grading | N/A | $4,000 to $16,205/acre |
| | Drainage Ditches | N/A | $1.27 to $6.04/linear foot |
| | Revegetation | N/A | $1,214 to $8,000/acre |
| **5.0** | **GROUND-WATER AND LEACHATE CONTROLS** | | |
| | Slurry Wall | $0.25 to $31.96/ft$^2$ | $4.50 to $13.86/ft$^2$ |
| | Grout Curtain | $6.60 to $14.00/ft$^2$ | $5.50 to $75.52/ft$^2$ |
| | Sheet Piling | N/A | $8.02 to $17.03/ft$^2$ |
| | Bottom Sealing by Grout | N/A | $9 to $116/ft$^2$ |
| | Permeable Treatment Beds | N/A | $14 to $267/ft$^2$ |
| | Well Point System | N/A | $803 to $8,284/well |
| | Deep Well System | N/A | $4,862 to $13,513/well |
| | Extraction/Injection Well System | N/A | $37.50/ vertical foot |
| | Extraction Wells/ Seepage Basin | $31,269/system | $33,618 to $53,360/system |
| | Subsurface Drain | $24 to $1,733/foot | $1.94 to $218/foot |
| **6.0** | **AQUEOUS AND SOLIDS TREATMENT** | | |
| | Activated Sludge | $6.3 million/mgd | $200,000 to $390,000/mgd |
| | Lagoons | N/A | $80,000 to $3.4 million/mgd |
| | Rotating Biological Contactors | N/A | $0.9 million to $29.6 million/mgd |
| | Air Stripping | $182,540/mgd | $607,000 to $7.3 million/mgd |
| | Carbon Treatment | $0.10 to $0.40/gallon | $14,132 to $643,000/mgd |
| | Oil/Water Seperator | $289,200/system | $12,720/mgd |

## TABLE 1
## RANGE OF UNIT COSTS ASSOCIATED WITH REMEDIAL TECHNOLOGIES (continued)

| | | |
|---|---|---|
| **7.0 GAS MIGRATION CONTROL** | | |
| Pipe Vents | N/A | $445 to $1,310/vent |
| Trench Vents | N/A | $ 35 to $646/linear foot |
| Gas Barriers | N/A | \$0.39 to \$3.00/ft$^2$ |
| Carbon Adsorption | $188/filter | $635/filter |
| **8.0 MATERIAL REMOVAL** | | |
| Excavation, Transport and Disposal | \$4.70 to \$884/yd$^3$ | \$379 to \$434/yd$^3$ |
| Hydraulic Dredging | N/A | \$1.25 to \$3.54/yd$^3$ |
| Mechanical Dredging | N/A | \$1.37 to \$4.09/yd$^3$ |
| Drum Handling | $60 to $1,528/drum | N/A |
| **9.0 WATER & SEWER LINE REHABILITATION** | | |
| Sewer Line Replacement | N/A | $53.90 to $141.60/linear foot |
| Sewer Line Repair/ Cleaning | $15/linear foot | $5.75 to $15.90/linear foot |
| Water Line Repair | N/A | $26 to $35.50/linear foot |
| Water Main Replacement | N/A | $58.50 to $119.18/linear foot |
| **10.0 ALTERNATIVE WATER SUPPLIES** | | |
| New Water Supply Wells | N/A | $46.25/linear foot |
| Water Distribution System | $1,091 to $10,714/house | N/A |

---

1 See individual technology sections for sources of cost data.

2 Unit Costs are exclusive of operations and maintenance costs. In some cases, no range is given since only a single data source was available.

N/A = Not Available.

## 1.5 FACTORS FOUND TO AFFECT COSTS

A fundamental concept of estimating costs of technology is that a variety of factors influence these costs. This compendium discusses these factors for each technology. This brief discussion of the effects of these factors reflects the descriptive detail given for each data source in the table of raw data. The essential site characteristics for actual expenditure data are typically described. These site characteristics are drawn from a hypothetical site scenario that is usually established for the purpose of making necessary assumptions for estimating costs. The level of detail available for actual site characteristics and hypothetical site scenarios varied widely.

## 1.6 CONSTANT 1982 DOLLARS

Since the source data, on which this compendium is based, originated in different years between 1975 and 1982, all costs were indexed to constant 1982 dollars using the Engineering News Record construction cost index. This index relects the weighted cost trend of common labor (74%), structural steel (15%), lumber (9%), and portland cement (2%). Data from 1983 documents were not deflated to 1982 dollars for two reasons. First, most of the costs for 1983 were actually incurred in 1982 or estimated for 1982 dollars. Second, the change in the ENR index between 1982 and 1983 is expected to be very small.

## 1.7 COST OF HEALTH AND SAFETY PROTECTION

One of the key factors affecting the costs of responses at uncontrolled sites is the level of protection for health and safety of on-site workers. The level of hazard determines the type of protective measures the workers must take, which ultimately affects the cost of the response. Many of the data sources used in this compendium, however, did not explicity note health and safety concerns. The cost data for actual expenditures include whatever protective measures were taken at the site. Often, however, the available information on the response action did not fully describe the protective measures. This defect may be corrected by further research. Health and safety assumptions for estimates are usually less clear than expenditures. In only one case did the estimator explicitly consider the cost effect of various protective measures.

SCS Engineers recently completed a study on the cost of health and safety protection for the U.S. EPA Office of Research and Development. Six cleanup firms were asked to bid on six hypothetical uncontrolled site scenarios with five levels of personal protection for the study (see Table 2). The key results are presented in Table 3,

## TABLE 2

## LEVELS OF PERSONAL PROTECTION

---

1. Level A - requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).
2. Level B - requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., below harmful concentration).
3. Level C - hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.
4. Level D - no identified hazard present, but conditions are monitored and minimal safety equipment is available.
5. No hazard protection - standard base construction costs.

---

Source: "Interim Standard Operating Safety Guides,"
EPA, 1982.

# TABLE 3

# AVERAGE PERCENT INCREASE FOR TOTAL COSTS AT FOUR DEGREE-OF-HAZARD LEVELS*

| Unit Operation | Level D | Level C | Level B | Level A |
|---|---|---|---|---|
| **Surface Water Controls:** | | | | |
| 1. Surface Sealing - Sythetic Membrane | 114% | 119% | 122% | 124% |
| 2. Surface Sealing - Clay | 109% | 119% | 124% | 127% |
| 3. Surface Sealing - Asphalt | -- | -- | -- | -- |
| 4. Surface Sealing - Fly Ash | -- | -- | -- | -- |
| 5. Revegetation | 117% | 124% | 126% | 128% |
| 6. Contour Grading | 122% | 133% | 140% | 146% |
| 7. Surface Water Diversion Structures | 135% | 144% | 151% | 154% |
| 8. Basins and Ponds | 125% | 138% | 145% | 150% |
| 9. Dikes and Berms | 150% | 173% | 176% | 186% |
| **Ground Water Controls:** | | | | |
| 1. Well Point System | 110% | 117% | 121% | 128% |
| 2. Deep Well System | -- | -- | -- | -- |
| 3. Drain System | 128% | 138% | 143% | 148% |
| 4. Injection System | -- | -- | -- | -- |
| 5. Bentonite Slurry Trench | 109% | 114% | 132% | 136% |
| 6. Grout Curtain | -- | -- | -- | -- |
| 7. Sheet Piling Cutoff | -- | -- | -- | -- |
| 8. Grout Bottom Sealing | -- | -- | -- | -- |
| **Gas Migration Controls:** | | | | |
| 1. Passive Trench Vents | -- | -- | -- | -- |
| 2. Passive Trench Barriers | -- | -- | -- | -- |
| 3. Active Gas Extraction Systems | -- | -- | -- | -- |
| **Waste Controls:** | | | | |
| 1. Chemical Fixation (Solidification) | 122% | 129% | 133% | 137% |
| 2. Chemical Injection | -- | -- | -- | -- |
| 3. Excavation of Wastes/Contaminated Soil | 307% | 337% | 397% | 715% |
| 4. Leachate Recirculation | -- | -- | -- | -- |
| 5. Treatment of Contaminated Water | 119% | 121% | 126% | 128% |
| 6. Drum Processing | 201% | 228% | 264% | 317% |
| 7. Bulk Tank Processing | 195% | 248% | 419% | 549% |
| 8. Transformer Processing | -- + | 293% | --+ | --+ |

* Values given include 100 percent for base construction costs.

+ This unit operation was deemed appropriate for performance only at Level C. Costs at Levels D, B, and A were not provided.

Source: "Worker Health and Safety Considerations: Cost of Remedial Actions at Uncontrolled Hazardous Waste Sites", Draft Final Report, 1983. SCS Engineers for U.S. EPA, Covington, Kentucky.

and more details are given in the SCS report. Several items should be kept in mind using Table 3: First, the results are from a final draft version of the SCS report. Additional changes may be made to the results. Second, the validity of the results depends on how seriously the bidders took the hypothetical scenarios and whether the bidders were neutral in providing the estimates (i.e., free from motives that may misrepresent the costs). And finally, the technologies in Table 3 do not always match the ones given in this compendium.

# SECTION 2

# 2.0 SURFACE WATER CONTROLS

## 2.1 SURFACE SEALING

### 2.1.1 Definition

Surface sealing (capping) involves covering a site with any of a variety of materials, including clay, asphalt, cement or a synthethic membrane, to prevent surface water infiltration, control erosion, and/or mitigate volatilization from contaminated waste.

### 2.1.2 Units of Measurement

Cost per unit surface area is used, generally, because area best expresses the functional attribute of a cap. Cost per square yard is used specifically because it is readily converted to acres (X 4,840), sq.ft. ($/9) and cubic yard volume (X depth in yards).

### 2.1.3 Summary Statistics

2.1.3.1 Expenditures

The actual costs of surface seals ranged from:

$0.92/yd.$^2$ - 4" thick, loam
to
$ 15.84/yd.$^2$ - 6" thick, clay.

The surface seals for which actual costs are given reflect site specific characteristics, such as design parameters and availability of local material. The most costly seal involved an engineered cap with carefully controlled clay/water content. The least costly cap was constructed with on-site clay that required only hauling and compacting.

Operation and maintenance costs included ground-water monitoring, inspection, surface upkeep and, possibly, costs of repair. These costs are accounted for separately where information on them exists.

### 2.1.3.2 Estimates

The eight cost estimates for surface seals ranged from:

$\$1.32/\text{yd.}^2$ - geotextile, level B protection
to
$\$16.88/\text{yd.}^2$- sand/hypalon/loam.

Operation and maintenance costs involving monitoring of ground-water and inspection of the cap were generally not included in the estimates. However, the following in costs for O&M were included in the Radian estimate:

| Item | Cost |
|---|---|
| Annual Inspection | \$500/year |
| Mowing/Revegetation | \$600/year/acre |
| Erosion control and drainage maintenance | \$200/year/acre |
| Repairs resulting from shrink swell or freeze/thaw forces construction | \$200 costs/year |

The extremes of the range of estimated costs are represented by a very simple temporary cap at the low end and a more complex, three element cap, intended to be permanent, at the highest cost end.

## 2.1.4 Factors Found to Affect Costs

### 2.1.4.1 Expenditures

Generally, cap and cap-related materials affected the costs of surface seals:

- Cap materials:

    bentonite/clay
    asphalt

    concrete

    synthetic membrane
    loam soil

- Cap-Related materials:

    top gravel
    curbs
    membrane soil anchor

The factors influencing the actual costs of surface seals, as outlined above and given in Table 4, are generally divided into "Material variations" and "Dimensional variations". They are presented here only to provide a rough background of the costs for general comparison purposes, and not to specifically delineate the proportional effect of particular cost components. It is not possible to determine from the data if there was a significant general cost difference between clay and asphalt caps. Although the costs at the California site suggest no significant cost difference, other sites had significant cost differences. These differences, however, may have been due to anomolous availability of local material or other factors. The number of observations were inadequate to make any clear conclusions. Variations in the costs for related materials may have affected the total costs of the various caps. The cost of the bentonite-soil cap at the California site included the cost of the 6-inch (0.15 m) cover of 3/4-inch (1.9 cm) gravel to prevent erosion of the cap. The cost of the curbs for run-off control at the California site was not included in the total reported cap cost, but curb installation may have caused an increase in the cost not incurred in the other sites lacking this feature. The use of a synthetic membrane required less heavy construction equipment for deployment, although soil anchors were used. The cap for the New Hampshire site may be considered an element of revegetation, but it also had a role in stabilization of the soil.

## TABLE 4
## SURFACE SEAL EXPENDITURES

(1982 Dollars)

| DATA SOURCE | MATERIAL | THICKNESS | COVERAGE | UNIT COST |
|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1981<br>Maryland | clay | 6 inches | data not available | $15.84 |
| US EPA<br>ELI/JRB<br>1981 | gravel over<br>bentonite-soil | 6 inches<br>4-6 inches | 17,333 sq.yd. | $10.98 |
| California | asphalt | data not available | 15,000 sq.yd. | $11.18 |
| US EPA<br>ELI/JRB<br>1980<br>Arkansas | clay | 1 foot | 11,111 sq.yd. | $10.09 |

## TABLE 4
## SURFACE SEAL EXPENDITURES (continued)

### (1982 Dollars)

| DATA SOURCE | MATERIAL | THICKNESS | COVERAGE | UNIT COST |
|---|---|---|---|---|
| US EPA<br>$CH_2$ M Hill<br>1981<br>New York | synthetic membrane | data not available | 216,600 sq.yd. | $3.75/sq.yd. |
| US EPA<br>Weston<br>1981<br>New Hampshire | loam soil for revegetation | 4 inches | 120,520 sq.yd. | $0.92/sq.yd. |
| US EPA<br>ELI/JRB<br>1983<br>Utah | clay - fabric | 2ft | 26,340 sq.yd. | $15/sq/yd |
|  |  |  |  |  |

Finally, dimensions cap (thickness and area covered) appeared to affect unit costs of the cap. Increased thickness and area of the cap generally added to costs by increasing the volume of cap material and the amount of grading required. An exact generalized function for this relationship cannot be determined from the available data. The unit cap cost, however, is also affected by economies of scale.

### 2.1.4.2 Estimates

Generally, the following factors affected the estimates:

- o Component material type:
    - clay
    - soil
    - synthetic liner
    - sand
- Number of components:
    - single component
    - composite
- Dimensional variations:
    - thickness
    - area covered

Generally, estimative information (see Table 5) was less detailed than the data for expenditures; however, salient information usually was available. Scenarios from generic engineering-construction manuals of cost (JRB, SCS, Radian) and feasibility studies were unable to predict unexpected changes occurring during the response.

Component material the costs were generally qualitative and quantitative. Four types of materials were assumed in the various estimates: clay, soil, synthetic liner and sand. The more significant consideration, however, was the number of components assumed for the estimates. Typically, additional component costs in composites were assumed to be additive. Again, the dimensional variations affected both the volume of surficial material required and the economies of scale. Increased cap thickness requires more volume per area. Caps with a larger area had the advantage of greater economies of scale, because previously mobilized grading and compacting equipment could be used at a relatively small additional marginal cost.

## TABLE 5
## SURFACE SEAL COST ESTIMATES

**(1982 Dollars)**

| DATA SOURCE | MATERIAL | THICKNESS | COVERAGE | UNIT COST |
|---|---|---|---|---|
| US EPA<br>JRB-RAM<br>1980 | loam over<br>hypalon over<br>sand | 8 inches<br>30 mil.<br>1 foot | 96,800 sq.yd. | $16.88/sq.yd. |
| US EPA<br>Radian<br>1982 | loam over<br>hypalon over<br>sand | 8 inches<br>30 mil.<br>1 foot | 96,800 sq.yd. | $9.34/sq.yd. |
| US EPA<br>SCS<br>"landfill"<br>1980 | bituminous concrete | 3 inches | 66,215 sq.yd. | $6.58-9.13/sq.yd |
| SCS<br>"impoundment"<br>1980 | bituminous concrete | 3 inches | 5,597 sq.yd. | $4.67-6.90/sq.yd. |

## TABLE 5
## SURFACE SEAL COST ESTIMATES (continued)

(1982 Dollars)

| DATA SOURCE | MATERIAL | THICKNESS | COVERAGE | UNIT COST |
|---|---|---|---|---|
| US EPA<br>MERL<br>1979<br>New Jersey | bituminous concrete | 3 inches | 5,597 sq.yd. | \$6.49/sq.yd . |
| US EPA<br>Weston<br>Feasibility Study<br>1982<br>New Hampshire | PVC liner | 30 mil. | 96,800 sq.yd. | \$4.50/sq.yd. |
| US EPA<br>$CH_2$ M Hill<br>Feasibility Study<br>1983<br>New Jersey | earthfill over geotextile | 8 inches<br>not given | 42,000 sq.yd. | \$1.83/sq.yd. |
| US EPA<br>$CH_2$ M Hill<br>1983<br>Arizona | geotextile | not given | not given | \$1.32/sq.yd. |

The Radian estimates given Table 6 are based on using the following list of cost components to construct a surficial seal, the same specifications were established in the JRB-RAM scenario.

TABLE 6. SURFACE SEAL COSTS: MATERIAL VARIATIONS

| Direct Capital Cost Items: | Cost |
|---|---|
| Topsoil (sandy loam), hauling, spreading, and grading (within 20 miles) | \$15/yd.$^3$ |
| Clay hauling, spreading, and compaction | \$10/yd.$^3$ |
| Sand hauling, spreading, and compaction | \$18/yd.$^3$<br>(\$9-12,000/acre) |
| Portland concrete (4 - 6" layer), mixed, spread, compacted on-site | \$9 - 15/yd.$^2$ |
| Bituminous concrete (4 - 6" layer), including base layer | \$4.50- 7.25/yd.$^2$ |
| Lime or cement, mixed into 5" cover soil | \$2.15 - 3.00/yd.$^2$ |
| Bentonite, material only; 2" layer, spread and compacted | \$1.90 yd.$^2$ |
| Sprayed asphalt membrane (1/4" layer and soil cover), installed | \$2.00 - 3.40/yd.$^2$ |
| PVC membrane (20 mil), installed | \$1.75 - 2.70/yd.$^2$ |
| Chlorinated PE membrane (20-30 mil), installed | \$3.25 - 4.30/yd.$^2$ |
| Elasticized polyolefin membrane, installed | \$3.10 - 4.15/yd.$^2$ |
| Hypalon membrane, (30 mil), installed | \$7.40/yd.$^2$ |
| Neoprene membrane, installed | \$7.25/yd.$^2$ |
| Ethylene propylene rubber membrane, installed | \$3.60 - 4.70/yd.$^2$ |
| Butyl rubber membrane, installed | \$3.60 - 5.10/yd.$^2$ |
| Teflon-coated fiberglass (TFE) membrane (10 mil), installed | \$23/yd.$^2$ |
| Fly ash and/or sludge, spreading, grading, and rolling | \$1.50 - 2.50/yd.2 |

## Expenditure Sources

- ELI/JRB Case Studies, 1983
- State and Federal Superfund Work, 1981 - 1983

## Estimate Sources

- JRB - RAM, 1980
- Radian, 1983
- EPA, OERR contractor Feasibility Studies, 1981 - 1983
- SCS Engineers, 1981

## 2.2 GRADING

### 2.2.1 Definition

Grading is the general term for the process of reshaping the surface of the ground to control surface-water runoff and infiltration, as well as to minimize erosion and prepare the site for revegetation or sealing of the surface. The three basic steps in the process are: hauling, spreading and compacting. The latter two steps are routinely practiced at sanitary landfills. The equipment and methods used in grading are essentially the same for all landfill surfaces, but applications of grading technology will vary on a site-specific basis. Grading is often performed in conjunction with surface sealing practices and revegetation as part of an integrated plan for the closure of a landfill.

### 2.2.2 Units of Measurement

The unit cost is given in dollars per acre because grading is usually performed on the scale of acres.

### 2.2.3 Summary Statistics

#### 2.2.3.1 Expenditures

No actual expenditure data were available for grading costs at this time.

#### 2.2.3.2 Estimates

The grading cost estimates ranged from:

$4,000/acre
to
$16,205/acre

Operation and maintenance costs involving ground-water monitoring and cap inspection were generally not included in the estimates. The following in O&M costs, however, were included in the Radian estimate;

| Item | Cost |
|---|---|
| Annual Inspection | $500/year |
| Mowing/Revegetation | $600/year/acre |
| Erosion control and drainage maintenance | $200/year/acre |
| Repairs resulting from shrink/ swell or freeze/thaw forces construction | $200 costs/year |

The lower grading cost estimates ($4,000 - 4,720/acre) reflected the costs of on-site hauling, spreading and compacting of a one-foot thick soil layer and a 6 inch sand layer. These estimates assume no material costs for sand or soil. The higher grading estimates by SCS also exclude material costs, but include the excavation and grading costs for on-site soil. Additional costs (30%) were included in these estimates to cover overhead and a contingency allowance. The cost for a diversion ditch, included in the SCS estimates, was subtracted, for consistency with the other estimates.

### 2.2.4 Factors Found to Affect Costs

#### 2.2.4.1 Expenditures

No expenditure data are available at this time.

#### 2.2.4.2 Estimates

The Following salient factors affected grading costs:

Material:

- Source of material
- Type of material

Related or additional costs:

- Soil compaction testing
- Surveying
- Overhead
- Contingency allowance

Two variables which affected costs of materials are detailed in Table 7. The source of the material was either on-site or off-site, which affected the costs for hauling. The type of fill material affected the estimate because sand costs more per unit volume to handle than soil. However, this estimated difference excludes material costs, and only includes hauling, spreading and compacting.

The inclusion of related or additional costs varied among the estimates, and hence affected the costs. The SCS estimates included the following related or additional costs, which were not included in the JRB and Radian estimates:

| Related/Additional Costs | Landfill (13.4 acres) | Impoundment (1.16 acres) |
|---|---|---|
| Surveying (2 days) | — | $ 366 - 614 |
| Overhead allowance (25%) | $17,499-20,402 | $2,655-3,469 |
| Contingency allowance (15%) | $10,502-12,237 | $1,593-2,077 |
| Total | $28,001-32,639 | $4,614-6,160 |

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983
- SCS, 1981

# TABLE 7
# GRADING COST ESTIMATES

### (1982 Dollars)

| DATA SOURCE | MATERIAL | COVERAGE | ADDED FILL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>SCS<br>"Impoundment"<br>1980 | on-site soil | 1.16 acres | 1.5 feet | $12,563-16,205/acre |
| US EPA<br>SCS<br>"Landfill"<br>1980 | on-site soil | 13.4 acres | 1 foot | $7,285-8,469/acre |
| US EPA<br>Radian<br>1983 | soil<br>sand | not given | not given | $4,000/acre |
| US EPA<br>JRB-RAM<br>1980 | "fill"<br>sand | 15 acres<br>20 acres | 1 foot<br>6 inches | $4,720 |

## 2.3 DRAINAGE DITCHES

### 2.3.1 Definition

Drainage ditches or trenches intercept overland flow or shallow ground-water flow to control surface discharge and/or minimize contributions to ground-water contamination. Ditches usually run around the perimeter of a site and may complement ground-water or surface-water control techniques by collecting water from subsurface drains or off of caps. They may be lined with a clay or synthetic membrane to prevent infiltration or with stone to prevent erosion.

### 2.3.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because length provides a single simple trench dimension for performing quick estimates.

### 2.3.3 Summary Statistics

#### 2.3.3.1 Expenditures

No actual expenditure data are available at this time.

#### 2.3.3.1 Estimates

The cost estimates range from:

| | |
|---|---|
| $1.27 - 2.54/LF | (1-foot deep) |
| to | |
| $6.04/LF | (6-feet deep) |

The cost estimates seemed to be primarily influenced by the volume of soil excavated. The Radian scenario assumed excavation of over six times as much soil as the EPA site-specific estimates. The 1 foot deep trench was similar to a shallow french drain since it was filled with gravel.

Operation and maintenance costs such as inspection and repair were not consistently available. The Radian estimate, however, gave the following estimate:

| Item | Cost |
|---|---|
| Annual Inspection | $500/year |
| Mowing/Revegetation | $600/year/acre |
| Erosion control and drainage maintenance | $200/year/acre |
| Repairs resulting from shrink/ swell or freeze/thaw forces construction | $200 costs/year |

### 2.3.4 Factors Found to Affect Costs

2.3.4.1 Expenditures

No expenditure data were available at this time.

2.3.4.2 Estimates

The three primary components affecting the cost estimates were:

Depth

Lining

Overhead and contingency costs

The depth was perhaps the most salient factor altering cost estimates (Table 8) since it was directly related to the volume of material excavated. Excavation is the primary task of ditch construction, grading and berm construction, but it was proportionally included in all estimates.

## TABLE 8
## DIVERSION DITCH COST ESTIMATES

(1982 Dollars)

| DATA SOURCE | LINING | DEPTH | TOTAL COST | UNIT COST |
|---|---|---|---|---|
| US EPA<br>Radian<br>1982 | none | 6 feet | $9,060 | $6.04/LF |
| US EPA<br>SCS (1)<br>"Landfill"<br>1980 | none | 6.5 feet | $13,393 -<br>$15,741 | $4.39-5.16/LF |
| US EPA<br>ORD-MERL<br>1979<br>New Jersey | gravel and stone filled | 1 foot | $8,763 | $1.27-2.54/LF |
| | | | | |

---

(1) Includes overhead (25%) and contingency allowance (15%).

Only the EPA-New Jersey site estimate delineated costs of the lining subtask. This cost component could become more significant for deeper ditches.

Finally, an overhead allowance (25%) and a contingency allowance (15%) were included for the SCS estimate. The other estimates did not include any surcharges or allowances for health and safety considerations, so these additional costs may be appropriate to include for some sites. The SCS estimate included "grubbing" to clear vegetation from ditches (28,300 sq.ft.) once a year at $378-779.

## Estimates Sources

- Radian, 1983
- SCS, 1981
- US EPA, OERR contractor Feasibility Studies

## 2.4 REVEGETATION

### 2.4.1 Definition

Re-establishing a vegetative cover may stabilize the surface of hazardous waste disposal sites, especially when preceded by surface sealing and grading. Revegetation decreases wind and water erosion, and contributes to the development of a naturally fertile and stable surface, and reduces infiltration by enhancing evapotranspiration (i.e., increased loss of soil moisture). It also can be used to aesthetically upgrade the appearance of disposal sites that are being considered for re-use. Short-term vegetative stabilization (i.e., on a semiannual or seasonal basis) also can be used during ongoing remedial actions.

### 2.4.2 Units of Measurement

Costs are given in dollars per acre because revegetation is usually given in terms of acres.

### 2.4.3 Summary Statistics

#### 2.4.3.1 Expenditures

No actual expenditure data are available at this time.

#### 2.4.3.2 Estimates

The revegetation cost estimates ranged from:

| | | |
|---|---|---|
| Capital: | $1,214/acre | (1.76 acre site) |
| | to | |
| | $8,000/acre | (20 acre site) |

Operation and Maintenance:

$51/acre/year

to

$1,267/acre/year

The range of costs for revegetation reflects the differences in the amount of work needed for different site conditions. The highest cost estimate was for a proposed restoration of a secondary growth, temperate, deciduous forest, requiring heavy liming to neutralize the highly acidic soil. The lowest cost was estimated for a hypothetically filled and graded fertile soil located on-site.

### 2.4.4 Factors Found to Affect Costs

#### 2.4.4.1 Expenditures

No actual expenditure data were available at this time.

#### 2.4.4.2 Estimates

The following factors were found to affect the revegetation cost estimates:

- Soil:
  - New fill and grading required
  - Terrain impediments (e.g., slope, berms)
  - treatment for fertility
- Vegetation:
  - Grass and/or trees (successional stage), multi-year planting
  - Mulching and/or jute mesh stabilization

The cost of soil was not included in the estimates (see Table 9). However, for the New Jersey Feasibility Study, 65,000 cubic yards of fill from off-site was expected to be necessary for the 72,600 square yard (15 acre) site (0.9 yards deep). Also, the SCS "landfill" estimate includes excavation, grading and recontouring of the site (27,685 $m^3$). This was about 60% of the total cost of revegetation, including the overhead and

## TABLE 9
## REVEGETATION COST ESTIMATES

(1982 Dollars)

| Data Source | Description | Soil | Size | Capital | Operation & Maintenance |
|---|---|---|---|---|---|
| US EPA<br>Feasibility Study<br>1983<br>New Jersey | grasses<br>trees: pine & hardwoods | acidic<br>fill cost separate neutralized | 15 acres | $8,000/acre | $1,267/acre/year (1) |
| US EPA<br>JRB - RAM<br>1980 | grasses,mulching<br>1,000 evergreens<br>1,000 shrubs | tilled loam | 20 acres (5 sloped 15 level) | $6,803 | $1,022 |
| US EPA<br>Radian<br>1982 | hydroseeding only (lime, fertilizer, field seed) | not given | not given: assume 17.5 acres | $1,791/acre | $829/acre/year |

### TABLE 9
### REVEGETATION COST ESTIMATES (continued)

(1982 Dollars)

| Data Source | Description | Soil | Size | Capital | Operation & Maintenance |
|---|---|---|---|---|---|
| US EPA<br>SCS<br>"Landfill" | grading<br>hydroseed,<br>mulching | fertile<br>soil<br>on-site | 13.4 acres | $6,420-<br>$7m889 (2) | $51/acre/year |
| US EPA<br>SCS<br>"Impoundment"<br>1980 | hydroseed,<br>mulching | fertile soil<br>on-site | 1.16 acres | $1,214-<br>$1,827/acre<br>(2) | $81-92/acre/year |

(1) First 5 years: $140,000; second 5 years: $50,000

(2) Includes overhead (25%) and contingency (10%)

contingency. The terrain was assumed to be flat in all estimates except for the JRB estimate, which assumed 25% sloped terrain and 75% flat terrain. The JRB estimate also assumed a three-year planting schedule. Different estimates vary as to the type of vegetation assumed. Hydroseeding was by far the least expensive means of revegetation ($0.37/sq. yd.) since it provides fertilizer, lime, and seed by mass application of a sprayed liquid. Trees and shrubbery cost significantly more because of higher material and labor costs of individual hand-planted nursery stock. This higher cost of plants will also vary with the type of stock selected. The Radian report provided the following list of various plant costs (in 1982 dollars), which included materials and installation:

| Item | Cost ($) |
|---|---|
| Topsoil, furnish and spread | |
| 4" | 1.43/sq.yd. |
| 6" | 1.90/sq.yd. |
| Sodding, 1-1/2" thick | |
| Level | 2.86/sq.yd. |
| Slopes | 3.74/sq.yd. |
| Ground Covers | |
| Pachysandra | 1.09/sq.ft. |
| Vinca Minor | 1.11/sq.ft. |
| Privits, 15" tall planted in hedge row | 2.34/LF |
| Barberry, 15" tall planted in hedge row | 3.03/LF |
| Boxwood 16", tall planted in hedge row | 2.84/LF |
| Trees and Shrubs | |
| Flowering Crab 8' - 10' | 222.12/ea |
| Hawthorn 8' - 10' | 170.90/ea |
| Junipers, spreading 18" - 24" | 33.22/ea |
| Junipers, upright 4' - 5' | 58.63/ea |
| Yews, spreading 18" - 24" | 45.22/ea |
| Yews, upright 2' - 3' | 54.63/ea |
| Rhododendron 2' | 71.16/ea |
| Fir 8' - 10' | 251.16/ea |
| Hemlock 8' - 10' | 283.16/ea |
| Beech 8' - 10' | 222.16/ea |
| Pine 8' - 10' | 249.16/ea |
| Tulip 8' - 10' | 244.16/ea |
| Maple 2" diameter | 197.15/ea |
| Maple 3" diameter | 362.24/ea |
| Sycamore 4' - 5' | 46.22/ea |
| Gold Locust | 69.22/ea |

Source: Radian, Inc., 1982

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983
- SCS, 1981
- US EPA, OERR contractor Feasibility Studies

## SECTION 3

## 3.0 GROUND-WATER AND LEACHATE CONTROLS

### 3.1 SLURRY WALL

### 3.1.1 Definition

A slurry wall is one of several types of subsurface cut-off walls that prevent leachate formation by redirecting upgradient ground-water away from a contaminated area, and/or controlling horizontal leachate movement away from the site. A slurry wall is constructed by filling a trench with a slurry such as bentonite on bentonite-soil-cement during excavation. The backfilled trench has a much lower coefficient of permeability than the surrounding soil and thus creates a barrier to flow of ground-water.

### 3.1.2 Units of Measurement

Costs are given in dollars per square foot because square feet reflect the functional area of a cut-off wall. In estimating the cost of a cut-off wall, the length and depth (facial area) requirements are usually fixed by the extent of the waste and the depth of the aquiclude. Linear units were not used because they would obscure the effect of depth on slurry wall costs.

### 3.1.3 Summary Statistics

3.1.3.1 Expenditures

The slurry wall expenditures ranged from:

$0.25/sq.ft.
to
$31.96/sq.ft.

The lowest cost for a slurry wall was for a privately constructed wall using extensive in-house equipment and labor. The next lowest cost wall was relatively shallow (14 feet deep). The highest cost slurry wall was built partly in contaminated soil on a stream bank. Each scoop of soil required analysis with an organic vapor analyzer and was disposed at an engineered landfill. The stream bank restricted and delayed access to the construction area. Operation and maintenance costs involved ground-water monitoring and, possibly, costs of repair. These costs were accounted for separately where information on them exists.

### 3.1.3.2 Estimates

Slurry wall cost estimates ranged from:

$4.50/sq.ft. soil-bentonite
to
$13.86/sq.ft.

The highest slurry wall cost estimate ($11.56/sq.ft.) was for a Wyoming bentonite slurry wall. The lowest estimate was for a competitively bid soil-bentonite slurry wall, for which another contractor was deemed more reliable. Operation and maintenance costs such as inspection, ground-water monitoring, and repair were not included in the estimates.

### 3.1.4 Factors Found to Influence Cost

#### 3.1.4.1 Expenditures

The following factors primarily affected slurry wall expenditures:

- Depth
- Thickness
- Wall material
- Inclusion of related costs:
    - Staging area set-up
    - Contaminated trench soil disposal

Perhaps the most salient factor affecting costs (shown in Table 10) was the wall material. Cement-soil-bentonite walls were the most expensive walls; soil-bentonite was in the middle of the cost range, and local clay was the least expensive. Much of the local clay used for the $1.80/sq.ft. California slurry wall was dredged from the adjacent bay. Depth affected costs since a larger excavator (such as a CAT 215 or clamshell instead of a backhoe) was necessary for digging deeper trenches. Once mobilized, however, larger equipment is capable of increasing the trench depth at a reduced marginal cost. Wall thickness was directly proportional to the volume of soil excavated and the volume of slurry mixed into the trench. Since costs are given in terms of dollars per square foot, the cost for this added volume is not precisely reflected in the face-area cost. However, most of the walls had very similar thicknesses, at between 30-36 inches, with two walls varying by two feet. The different thicknesses generally stem from different requirements set forth in a consent decree state or federal agency mandate, and usually account for the variable permeabilities of different slurry wall materials.

Other related costs played a significant role in at least two cut-off walls. At the Pennsylvania site, a large volume of contaminated trench soil required disposal at an engineered landfill. Adding to these disposal costs, was the need to test each excavator scoop with an organic vapor analyzer, which slowed trench construction.

# TABLE 10
# SLURRY WALL EXPENDITURES

(1982 Dollars)

| DATA SOURCE | LENGTH & DEPTH | THICKNESS | MATERIAL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1981<br>Pennsylvania | 648 feet<br>x<br>17 feet | 1 foot | cement-<br>bentonite | $31.96/sq.ft. |
| US EPA<br>JRB/ELI<br>1979<br>Colorado | 1,500 feet<br>x<br>20 feet | 30 inches | 85% soil-<br>bentonite;<br>15% cement | $8.33/sq.ft. |
| US EPA<br>JRB<br>Florida A<br>(Date unknown) | 2,290 feet<br>x<br>30 feet | 30 inches | soil-<br>bentonite | $5.88/sq.ft. |
| US EPA<br>$CH_2$ M Hill<br>1982<br>New Hampshire | 3,500 feet<br>x<br>60 feet | 3 feet | soil-<br>bentonite | $5.64/sq.ft. |

## TABLE 10
## SLURRY WALL EXPENDITURES (continued)

(1982 Dollars)

| DATA SOURCE | LENGTH & DEPTH | THICKNESS | MATERIAL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>JRB<br>(Date unknown)<br>Louisiana | 1,500 feet x 20 feet | 3 feet | soil-bentonite | $2.78/sq.ft. |
| US EPA<br>JRB<br>(Date unknown)<br>Florida B | 2,900 feet x 20 feet | 3 feet | soil-bentonite | $2.60/sq.ft. |
| US EPA<br>ELI/JRB<br>(1983 Dollars)<br>California | 2,765 feet x 14 feet | 5 feet | local clay | $1.42/sq.ft. |
| US EPA<br>ELI/JRB<br>1980<br>Arkansas | 2,306 feet x 48 feet | 3.2 feet | local clay | $0.25/sq.ft. |
| US EPA<br>ELI/JRB<br>1983 | 2360 ft x 30 ft | 3 ft | soil - bentonite | $3.80/sq.ft. |

The cost given at the Arkansas site may not reflect all slurry wall costs since significant in-house labor and equipment were used but not recorded. Other related costs such as site preparation and geotechnical investigations were inconsistently noted as separate or included. Generally, these costs were excluded from the slurry wall expenditures.

### 3.1.4.2 Estimates

The following factors affected the estimated costs for slurry walls:

- Depth
- Thickness
- Material
- Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingencies

Material costs were again the most clear cost factor in the slurry wall cost estimates (Table 11). The highest cost wall ($10/sq.ft.) was the cement-bentonite wall at the New York site. Slurry wall depth seemed to be, at best, a secondary factor. The deepest (130 foot deep) slurry wall at the New Jersey site was the second to least costly while the shallowest (14 foot) slurry wall was the most costly.

However, the construction of the 130 foot deep slurry wall would be greatly facilitated by the coastal plain sediment of New Jersey for which it was proposed. Complete hydrogeological assumptions were not given for all of the estimation scenarios, but a 1980 paper by Ressi di Cervia (see Table 12) gave the following depth-soil condition cost matrix. The slurry wall thicknesses varied less than did those of the wall studied for the actual expenditures. Only one hypothetical slurry wall was over 3 feet thick.

## TABLE 11
## SLURRY WALL COST ESTIMATES

(1982 Dollars)

| DATA SOURCE | LENGTH & DEPTH | THICKNESS | MATERIAL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>$CH_2$ M Hill<br>1983<br>New York | 7,900 feet<br>x<br>14 feet | over 2 feet | concrete | $10/sq.ft. |
| US EPA<br>Weston<br>1982<br>New Hampshire | 3,733 feet<br>x<br>70 feet (1) | 3 feet | soil-<br>bentonite | $8.05/sq.ft. |
| US EPA<br>Bids<br>1982<br>New Hampshire | 3,500 feet<br>x<br>60 feet | 3 feet | soil-<br>bentonite | $7.35/sq.ft. |
| US EPA<br>JRB-RAM<br>1980 | 1,000 feet<br>x<br>40 feet | 3 feet | soil-<br>bentonite | $7.08-13.86/sq.ft. |

(1) Dimensions assumed for costing
(3,125 feet x 50 feet expected).

# TABLE 11

## SLURRY WALL COST ESTIMATES (continued)

## (1982 Dollars)

| DATA SOURCE | LENGTH & DEPTH | THICKNESS | MATERIAL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>Radian<br>1982 | 100 feet<br>x<br>40 feet | 4 feet | soil-<br>bentonite | \$6.94/sq.ft. |
| US EPA<br>$CH_2$ M Hill<br>1983<br>New Jersey Site A | 114,715 sq.ft. | 24-30 inches | soil-<br>bentonite (5%) | \$6/sq.ft. |
| US EPA<br>SCS<br>"Impoundment"<br>1980 | 911 feet<br>x<br>49 feet | 3.28 feet | Wyoming<br>bentonite-<br>water (1:12) | \$6.49-11.56/sq.ft. |
| US EPA<br>SCS<br>"landfill"<br>1980 | 2,362 feet<br>x<br>49 feet | 3.28 feet | bentonite-<br>water (1:12) | \$6.02-10.50/sq.ft. |

## TABLE 11
## SLURRY WALL COST ESTIMATES (continued)

(1982 Dollars)

| DATA SOURCE | LENGTH & DEPTH | THICKNESS | MATERIAL | UNIT COST |
|---|---|---|---|---|
| US EPA<br>Bids<br>1982<br>New Hampshire | 3,500 feet<br>x<br>60 feet | 3 feet | soil-<br>bentonite | $5.44/sq.ft. |
| US EPA<br>CDM, Inc.<br>1983<br>New Jersey Site B | 4,257 feet<br>x<br>130 feet | not given | soil-<br>bentonite | $4.88/sq.ft. |
| US EPA<br>Bids<br>1982<br>New Hampshire | 3,500 feet<br>x<br>60 feet | 3 feet | soil-<br>bentonite | $4.50/sq.ft. |
|  |  |  |  |  |

## TABLE 12

## SLURRY WALL COSTS: DEPTH EFFECTS

| | Slurry Trench Prices In 1982 Dollars Soil Bentonite Backfill (Dollars/Square Foot) | | | Unreinforced Slurry Wall Prices in 1982 Dollars Cement Bentonite Backfill (Dollars/Square Foot) | | |
|---|---|---|---|---|---|---|
| | Depth 30 Fee | Depth 30-75 Feet | Depth 75-120 Feet | Depth 60 Feet | Depth 60-150 Feet | Depth 150 Feet |
| Soft to Medium Soil N 40 | 3-5 | 5-10 | 10-13 | 19-25 | 25-38 | 38-95 |
| Hard Soil N 40 - | 5-9 | 6-13 | 13-25 | 32-38 | 38-51 | 51-121 |
| Occasional Boulders | 5-10 | 6-10 | 10-32 | 25-38 | 38-51 | 51-108 |
| Soft to Medium Rock, Sandstone, Shale N 200 | 8-15 | 13-25 | 25-64 | 64-76 | 76-108 | 108-222 |
| Hard Rock Granite, Gneiss, Schist* | — | — | — | 121-178 | 178-222 | 222-298 |

Notes: N = standard penetration value in number of blows of the hammer per foot of penetration (ASTM D1586-67)

*Normal Penetration Only

For standard reinforcement add $8.00 per sq. ft.
For construction in urban environment add 25% to 50% of price

Reference: Ressi di Cervia 1980.

Additional costs were included in at least two of the estimates. Both geotechnical investigation (impoundment: $11,210-23,010; landfill: $4,543-7,694) costs and overhead (25%) and contingency costs (30%) were included in the SCS estimates. Geotechnical investigation and permeability testing costs were grouped together ($23,600-94,400) in the JRB estimate.

Expenditure Sources

- ELI/JRB Case Studies, 1983
- JRB, 1983
- State and Federal Superfund Work

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983
- SCS, 1981
- US EPA, OERR, Feasibility Studies.

## 3.2 GROUT CURTAINS

### 3.2.1 Definition

Generally, grouting is the injection under pressure of one of a variety of special fluids into a rock or soil body to seal and strengthen that body. Once this fluid gels in the rock or soil voids, it greatly reduces the permeability of, and increases the mechanical strength of the grouted mass. When carried out in the proper pattern and sequence, this process can result in a curtain or wall that can be a very effective ground-water barrier. Grouting is rarely used when ground-water has to be controlled in soil or loose overburden. The major use of curtain grouting is to seal voids in porous or fractured rock where other methods of ground-water control are impractical. The injection process itself involves drilling holes to the desired depth and injecting the grout with the use of special equipment. A line of holes is drilled in single, double, or sometimes triple staggered rows (depending on the site characteristics) and injecting the fluid in either descending stages with increasing pressure, or ascending stages with decreasing pressure. The spacing of the injection holes is also site-specific and is determined by the penetration radius of the grout out from the holes. Ideally, the grout injected in adjacent holes should fuse between them. If this process is done properly, a continuous, impervious barrier (curtain) will be formed.

### 3.2.2 Unit of Measurement

Costs are given in terms of dollars per unit face-area (square feet) because it best reflects the functional area of the grout curtain. The effect of other dimensions on costs is discussed in section 3.2.4 (Factors Found to Affect Costs). Since the units used in existing engineering estimates have varied widely, the effect of using different dimensions is an important consideration for comparing estimates.

### 3.2.3 **Summary Statistics**

#### 3.2.3.1 Expenditures

The cost of grout curtains (all-ASPEMIX* vibrating beam walls) ranged from:

$ 6.60/sq.ft.
to
$ 14/sq.ft.

The lowest cost grout curtain was the first one installed by a new company. The $14/sq.ft. grout curtain was installed two years later at the same site as the $8.26/sq.ft. wall. The cost differences may reflect the need to recoop the potential earnings foregone for the earlier walls in order to enter the market. Operation and maintenance costs such as inspection, ground-water monitoring and, possibly, repair either were accounted for separately or were not yet encountered at the new sites.

#### 3.2.3.2 Estimates

The grout curtain cost estimates ranged from:

| | |
|---|---|
| $5.50/sq.ft. | ASPEMIX, vibrating beam installation |
| to | |
| $75.52/ sq.ft. | phenolic resin, standard injection installation |

The order of magnitude difference in cost estimates for grout curtain cost estimates largely seems to reflect the widely varying thicknesses. The highest estimate was for a 9 foot thick wall; while the lowest (group of four) estimate was for an ASPEMIX wall, which is typically under a foot thick. Operation and maintenance costs such as inspection and ground-water monitoring costs were not included in the estimates.

* Note: The ASPEMIX technique involves injection of a manufactured compound, and for this reason it is included on the Grout Curtain section. Alternatively, it could be placed in the Slurry Wall section, as the vibrated beam acts to produce a trench similiar to that used in slurry wall construction.

### 3.2.4 Factors Found to Affect Costs

#### 3.2.4.1 Expenditures

The following factors seemed to affect expenditures:

- Market entry losses
- Labor costs.

The cost of grout curtains seemed to be primarily affected by market conditions. The industrial contacts who supplied the data in Table 13 noted that, compared to the costs shown, the prices will decrease and stabilize in the future now that the firm has penetrated the market. They also noted that the cost at the California site was significantly affected by the relatively high local labor costs. For contrast, a privately built grout curtain in Dallas, for which no data were available, was said to have cost less than half the latest California wall.

#### 3.2.4.2 Estimates

The following factors affected grout curtain cost estimates:

- Thickness
- Material composition
- Installation technique
- Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingency.

The most significant cost factor affecting grout curtain cost estimates (Table 14) was the wall thickness. This was assumed to be equal to the center-to-center distance of the grout injections for single row walls, which is equal to the diameter for adjacent injections. The nine foot thick wall, which was expected to be necessary to enclose an impoundment, was the highest estimate.

## TABLE 13
## GROUT CURTAIN EXPENDITURES

(1982 Dollars)

| Data Source | Length x Depth | Thickness | Material | Unit Cost |
|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>California<br>1982 | 2,929 feet<br>x<br>17 feet | 0.83 feet | ASPEMIX (1) | $14/sq.ft. |
| US EPA<br>ELI/JRB<br>California<br>1980 | 2,000 feet<br>x<br>17 feet | 0.83 feet | ASPEMIX (1) | $8.26/sq.ft. |
| US EPA<br>ELI/JRB<br>Michigan<br>1980 | 1,465 feet<br>x<br>10 feet | 1 foot | ASPEMIX | |

(1) Asphalt, concrete and sand emulsion installed with vibrating beam

# TABLE 14
# GROUT CURTAIN COST ESTIMATES

## (1982 Dollars)

| Data Source | Length x Depth | Thickness | Material | Unit Cost |
|---|---|---|---|---|
| SCS "Impoundment" 1980 | 902 feet x 49 feet | 9 feet | phenolic resin | $38.94-75.52/sq.ft. |
| SCS "Landfill" 1980 | 7,117 feet x 49 feet | 5 feet | phenolic resin | $33 - 68.44/sq.ft. |
| US EPA JRB/RAM 1982 | 800 feet x 20 feet | 3 feet | silicate | $11.54 - 17.17/sq.ft. |
| US EPA Radian 1982 | 1,000 feet x 20 feet | 3 feet | silicate | $21.80/sq.ft. |
| | | | portland cement | $ 11.80/sq.ft. |

## TABLE 14
## GROUT CURTAIN COST ESTIMATES (continued)

**(1982 Dollars)**

| Data Source | Length x Depth | Thickness | Material | Unit Cost |
|---|---|---|---|---|
| US EPA<br>ORD - MERL<br>1979<br>New Jersey | 4,600 feet<br>x<br>40 feet | 3 feet | not given | $6.22 - 10.48/sq.ft. |
| US EPA<br>4 bids<br>1982<br>New Hampshire | 3,500 feet<br>60 feet | not given<br>(assume 1 foot) | ASPEMIX | $5.50-$6.86/sq.ft. |

Comparing the cost estimates based on dollar-per-linear-foot and a dollar-per-cubic-foot basis is useful for discerning the effect of thickness on the estimates. The following list shows that the cost ranking is aberrant compared to the depths when measured on a cost-per-linear-foot basis.

| Date | Depth | Unit Cost | Cost Ranking ($/sq.ft.) |
|---|---|---|---|
| 1982 | 60 feet | $ 330-412/ LF | 6 |
| 1980 | 49 feet | $1,908-3700/LF | 1 |
| 1980 | 49 feet | $1,619-3353/LF | 2 |
| 1979 | 40 feet | $ 249-419/ LF | 5 |
| 1982 | 20 feet | $ 230-340/ LF | 4 a |
| 1982 | 20 feet | $ 420/LF | 3 |
| 1982 | 20 feet | $ 240/LF | 4 b |

The costs show neither an ordinated ranking according to depth, nor do they show an evenness (X= $1,102/LF; SE= $365/LF; n=12) that would suggest that simple length was the most significant cost factor.

Similarly, the effect of thickness and depth on cost can be elucidated by comparing costs on a per-volume basis. The following list shows that the cost estimates are relatively even (X= $5.30/cu.ft.; SD= $2.90/cu.ft.; n= 12).

| Date | Thickness | Unit Cost | Cost Ranking ($/sq.ft.) |
|---|---|---|---|
| 1980 | 9 feet | $4.33-8.26/cu.ft. | 3 |
| 1980 | 5 feet | $6.61-13.69/cu.ft. | 1 |
| 1982 | 3 feet | $7.30/cu.ft. | 2 |
| 1982 | 3 feet | $3.80-5.72/cu.ft. | 4 a |
| 1982 | 3 feet | $3.90/cu.ft. | 4 b |
| 1979 | 3 feet | $2.03-3.43/cu.ft. | 5 |
| 1982 | 1 foot | $5.50-6.86/cu.ft. | 6 |

The data are inadequate to provide any accurate generalization about the relative costs of various grout materials. Plans for use of phenolic resin for grout curtains, gave rise to the two highest estimates; two plans for silicate walls were each more costly than plans for portland cement walls, and four bids to construct an ASPEMIX wall, composed of an emulsion of asphalt, sand and concrete to be installed with a vibrating beam, were the least costly. Since no "control" estimate was available to contrast the cost of an ASPEMIX wall installed with a traditional injection technique as opposed to the prescribed installation technique, techniques and materials cannot be separately judged as to their individual costs. However, the vibrating beam method may be generally less expensive than the traditional injection technique.

Finally, the cost of a geotechnical investigation was included only in the JRB and the SCS estimates. The SCS estimate also included overhead (25%) and contingency allowance (30%).

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983
- US EPA, OERR contractor bids
- SCS, 1980

## 3.3 SHEET PILING

### 3.3.1 Definition

Sheet piling can be used to form a continuous ground-water barrier of driven steel piles. Although sheet piles can also be made of wood or precast concrete, steel is the most effective in terms of cutting off ground-water and ease of installation. The construction of a steel sheet piling cut-off wall involves driving interlocking piles into the ground using a pneumatic or steam-driven pile driver. In some cases, the piles are pushed into pre-dug trenches. Piles are commonly 4 to 40 feet long and 15 to 20 inches wide. Because of corrosion and leaky joints usually present between piles, this method is often considered a temporary stop-gap measure.

### 3.3.2 Unit of Measurement

Costs are given in terms of dollars per square foot because area best reflects the functional units of a cut-off wall.

### 3.3.3 Summary Statistics

#### 3.3.3.1 Expenditures

No actual expenditure data for sheet piling cut-off walls were available at this time.

#### 3.3.3.2 Estimates

The cost estimates for sheet piling cut-off walls ranged from:

$8.02/sq.ft.
to
$17.03/sq.ft.

The largest site, which was constructed with 116,228 sq.ft. of sheet piling, produced the lowest estimate for a sheet piling cut-off wall. Costs-per-square-foot of the large wall was effectively reduced because the cost of mobilization of equipment (a fixed cost) could be spread over a larger surface area.

## 3.3.4 Factors Found to Affect Costs

### 3.3.4.1 Expenditures

No actual expenditure data are available at this time.

### 3.3.4.2 Estimates

The following components affected the cost estimates for sheet piling cut-off walls:

- Economies of scale
- Piling type
- Inclusion of related costs:
  - Geotechnical investigation
  - Overhead and contingency allowances

As noted above in Comments on the summary statistics, the limited data in Table 15 suggest that economies of scale may be the most significant factor affecting costs. Experienced personnel using specialized equipment (e.g., pile drivers) may be able to install sheet piling at decreasing cost-per-unit area as the total area of installed wall increases. This is due to the high cost of mobilization and erection of sheet piling as compared to other remedial technologies.

Among the estimate scenarios, the piling types varied both in composition and in thickness. Galvanized steel ($10.48/sq.ft. installed) which provides somewhat greater corrosion resistance, was slightly more expensive than black steel ($9.41/sq.ft. installed). The paucity of data on piling thicknesses precludes accurate quantification of their relationships to costs. However, this variable may often be dictated by the availability of local material and geological constraints. Piles are typically withdrawn and reused, and the thickness of the piles may affect the reusability. Hence the rebate value of piles is affected, since a pile which is too thin may buckle upon insertion. The effect of thickness and reusability on the cost may be significant since materials may be 80% of the total cost of a sheet piling cut-off wall. The cost estimates given Table 14 do not include cost credits for reuse of the piles, but do include varying pile types, as indicated. The cost of a geotechnical investigation as noted in Table 15 ($11,210-23,010) was included only in the SCS "impoundment" estimate. Additional costs for overhead (25%) and contingency allowances (25%) were included in this estimate and the SCS "landfill" estimate.

## Estimates Sources

- JRB-RAM, 1980
- Radian, 1983
- SCS, 1980

## TABLE 15
## SHEET PILING COST ESTIMATES

(1982 Dollars)

| Data Source | Lenth x depth | Weight | Piling | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | 1,000 feet<br>x<br>20 feet | 186 tons | 5 guage | $17.03/sq.ft. |
| US EPA<br>Radian<br>1982 | 1,000 feet<br>x<br>20 feet | Not given | black steel<br>galvanized | $9.41/sq.ft.<br>$10.48/ sq.ft. |
| US EPA<br>SCS (1, 2)<br>"Impoundment"<br>1980 | 2,372 feet<br>x<br>49 feet | 487 tons | 5 guage | $8.42-12.63/sq.ft. |
| US EPA<br>SCS (2)<br>"Landfill"<br>1980 | 2,373 feet<br>x<br>49 feet | 1,281 tons | PMP-22 | $8.02-11.80/sq.ft. |

(1) Includes geotechnical investigation ($11210 - 23,010)

(2) Includes overhead (25%) and contingency (25%) allowances

## 3.4 BOTTOM SEALING BY GROUTING

### 3.4.1 Definition

Bottom sealing by grouting is a direct technique for installing a barrier to downward leachate migration. Grout is injected through the fill material to form a bottom underneath the contaminants. The grout is injected horizontally from jets at the bottom of a pipe, which is inserted with a pneumatic hammer. A grid of injected grout forms a contiguous bottom seal. Grout materials are typically silicate or portland cement.

### 3.4.2 Units of Measurement

Costs are given in terms of dollars per square foot because area best reflects the functional characteristics of bottom sealing.

### 3.4.3 Summary Statistics

3.4.3.1 Expenditures

No actual expenditure data are available at this time.

3.4.3.2 Estimates

The grout bottom sealing costs ranged from:

$9/sq.ft.
to
$116/sq.ft.

This wide range of estimates seems to reflect the varying thicknesses given for hypothetical seals. The higher estimate was for a 5.25-foot thick seal vs. a 3.25-foot thick seal for the lower estimate.

### 3.4.4 Factors Found to Affect Costs

#### 3.4.4.1 Expenditures

No actual expenditure data are available at this time.

#### 3.4.4.2 Estimates

In the designs used for the grouting estimates, the following components varied:

- Grout thickness
- Grout material
- Coverage
- Soil, fill type

Of these components, the thickness of grout appeared to be on direct proportion to the variation in the cost of the two grouting seals shown in Table 16. The "landfill" seal was 2 feet (61%) thicker than the "impoundment" grout. Thickness appears to affect the estimates more than does the type of grouting material. Material costs for phenolic resin are significantly higher than for portland cement grout, but overall, a thicker cement grout is required for a wall of equivalent permeability.

Economies of scale may have caused the "landfill" grouting to be less expensive on a cost per-unit-area basis than the impoundment grouting since the landfill scenario assumed ten times as much coverage. Despite this disparity in task size, the geotechnical investigation (impoundment: $11,210-23,010; landfill: $15,104-25,559) and equipment cost were relatively similar.
Overhead (25%) and contingency allowances (40%) were the same for both seals.

The effect of injection through heterogeneous, resistant fill and soil probably is a significant cost factor in the "landfill" estimates, although it is impossible to quantify from the available information.

Estimates Source

SCS 1980

## TABLE 16
## GROUT BOTTOM SEALING ESTIMATES

(1982 Dollars)

| Data Source | Grout Material Thickness | Depth | Coverage | Unit Cost |
|---|---|---|---|---|
| US EPA<br>SCS<br>"landfill"<br>1980 | cement<br>5.25 feet | 49 feet | 559,704 sqft | $60 - $116/sq.ft. |
| US EPA<br>SCS<br>"Impoundment"<br>1980 | phenolic resin<br>3.28 feet | 49 feet | 5,038 sqft | $9 - $18/sq.ft. |

## 3.5 PERMEABLE TREATMENT BED

### 3.5.1 Definition

A permeable treatment bed is subsurface bed or wall of a permeable filtering material, typically constructed as a trench back-filled with activated carbon or limestone, which is designed to decontaminate shallow ground-water as it flows through the bed. It is most unusual to "precipitate metalic ions!" This may be the latest on potential energy storage systems, since ions are, by definition, charged particles (this renders them soluable)!

The principal constituent of Calcium carbonate, chemically acts to neutralize acidic ground-water. Metal ions, once quite soluable in the more acidic ground-water, form insoluable metal liquids or precipitates as the ground-water becomes more alkaline. Alternatively, metals and organics are both removed by physical and chemical forces through the use of activated carbon, which, through its high surface area to volume ratio and large number of available surface sites, absorbs dissolved molecules directly from the ground-water. The six primary component tasks of treatment beds (generally included in the costs) are:

- Trench excavation
- Spreading
- Well-point dewatering
- Sheet piling
- Walers, connectors, struts
- Bedding (limestone or carbon).

Permeable treatment beds represent a developmental remedial technology, the costs of which are not well documented to date.

### 3.5.2 Units of Measurement

Costs of permeable treatment beds are given in terms of dollars per square foot because it best expresses the functional value of the treatment bed. The width and depth of the leachate plume for which a bed is to be estimated are usually known.

### 3.5.3 Summary Statistics

#### 3.5.3.1 Expenditures

No actual expenditure data for permeable treatment was available at this time.

#### 3.5.3.2 Estimates

The cost estimate for permeable treatment beds ranged from:

| | |
|---|---|
| $14/sq.ft. | limestone bedding |
| to | |
| $267/sq.ft. | activated carbon bedding |

The least costly permeable treatment bed was for a limestone bed; whereas the high estimate was for a bed of granular activated carbon. Operation and maintenance costs, when given, consisted of the following two cost items which depend on site specific variables:

| | Operation and maintenance Cost Items | Site-specific Variables |
|---|---|---|
| (1) | Ground-water monitoring cost | - contaminants<br>- hydrogeologoy |
| (2) | Replacement cost | - operational lifetime of treatment bed |

### 3.5.4 Factors Found to Affect Costs

#### 3.5.4.1 Expenditures

No actual expenditure data are available at this time.

#### 3.5.4.2 Estimates

The following factors were found to affect the treatment bed estimates:

- Bedding Material
- Size

The estimates made by JRB and Radian shown in Table 17 are very similar except that 17% was added to most of the Radian costs for inflation. However, the same unit cost for limestone and carbon was assumed. The bedding cost was the most significant (90%) no-cost out of the total for the carbon treatment bed. The most significant cost (75%) for the limestone treatment bed was the cost of sheet piling. Conversely, the bedding cost was 7% of the total for the limestone bed; whereas for the carbon bed, the sheet piling was 8% of the total cost.

Although all estimates of cost are for treatment beds of the same size, the influence of size on unit costs should be noted briefly: First, increases in the dimensions of the bed generally will proportionately increase total costs of the treatment bed. The effect is more pronounced with simultaneous increases in width and depth, in proportion to the incremental change of width mutiplied by the incremental change in depth. The cost of a larger carbon trench could be significantly different than any of the estimates given in Table 17 due to the high cost of activated carbon. Second, economies of scale could reduce the unit costs of limestone treatment beds over that given in the estimate, since reusable sheet piling, which has significant one-time set up and mobilization costs, is the major (75%) component cost. Also, the marginal unit cost of dewatering decreases as trench size increases.

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983

## TABLE 17

## PERMEABLE TREATMENT BED COST ESTIMATES

(1982 Dollars)

| Data Source | Area | Width | Bed Material | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | 1,000 feet<br>x<br>20 feet | 4 feet | activated carbon bed | $267/sq.ft |
| US EPA<br>Radian<br>1983 | 1,000 feet<br>x<br>20 feet | 4 feet | coarse size activated carbon | $201/sq.ft. |
| US EPA<br>JRB-RAM<br>1980 | 1,000 feet<br>x<br>20 feet | 4 feet | "gravel and sand sized" limestone | $29/sq.ft. |
| US EPA<br>Radian<br>1980 | 1,000 feet<br>x<br>20 feet | 4 feet | "gravel and sand sized" limestone | $14-14.67/ sq/ft. |

## 3.6 WELL POINT SYSTEM

### 3.6.1 Definition

Well points are generally used to lower the water table or extract leachate. They differ from drilled and cased deep wells in that they are driven, instead of drilled, into the ground to just below the leachate plume. Ground-water is then piped to a suction header, drawn by a centrifugal pump, to a treatment system. In contrast, deep wells typically use submersible pumps to pump ground-water to a treatment system. Treatment costs for costing purposes, are considered separately.

### 3.6.2 Units of Measurement

Costs are given in terms of dollars per well. The extraction rate (gallons per minute-gpm) and depth should also be considered. Since these characteristics vary with site- specific hydrology, however, costs given below do not account for pumping rate.

### 3.6.3 Summary Statistics

#### 3.6.3.1 Expenditures

No actual expenditure data are available at this time.

#### 3.6.3.2 Estimates

The cost estimates ranged from
$803/well
to
$8,284/well

The highest cost estimate (SCS-"impoundment") included the cost of geotechnical investigation, which comprised 50% of the costs. No related costs were included in the lowest estimate (Radian).

### 3.6.4 Factors Found to Affect Costs

#### 3.6.4.1 Expenditures

No expenditure information are available at this time.

#### 3.6.4.2 Estimates

The following factors affected the cost estimates for the well point systems:

- Depth
- Pumping rate
- Related costs:
  - Geotechnical investigation
  - Overhead allowances
  - Contingency allowances

The costs shown in Table 18 are relatively similar. The effect of depth, which was expected to be an important cost factor, did not significantly affect the estimates. Although installation of well point is often charged by the depth, well installation was a relatively small component of cost compared to pumps and headers. Hence, depth affected cost estimates in proportion to the impact of well point installation on total costs, which was a small fraction of the total. The pumping rate, which varied with the size of the pumps and the header system, should affect both capital, operation and maintenance costs. However, no relationship could be identified in the data.

The most significant cost factors that could be identified were the related costs. Over half of the SCS "Impoundment" estimate was for a geotechnical investigation, that was not included in either of the other estimates. The SCS "Impoundment" and "Landfill" estimates included overhead (25%) and contingency (25%) allowances.

Estimates Sources

- Radian, 1983
- SCS, 1980

# TABLE 18

# WELL POINT SYSTEM COST ESTIMATES

(1982 Dollars)

| Data Source | # Wells; Depth; Diameter | Pumping rate Aquifer depth | Operation & Maintenance | Capital Unit Cost |
|---|---|---|---|---|
| US EPA<br>SCS<br>1980<br>"Impoundment" | 5 wells<br>16 feet deep<br>-- | --<br>-- | \$9,160-<br>\$9,970/year<br>10,000 kwh | \$4,413-\$8,284/well<br>(1) |
| US EPA<br>SCS<br>1980<br>"Landfill" | 133 wells<br>16 feet deep<br>-- | 291-396 gpm<br>-- | \$10,460-<br>\$11,270/year<br>36,000 kwh | \$1,109-\$1,855/well<br>(2) |
| US EPA<br>Radian<br>1983 | 50 wells<br>25 feet<br>4 inches | 500 gpm<br>10 feet | \$70.88/Mgd | \$803/well |
| | | | | |

(1) Includes geotechnical investigation cost (55%)
(2) Includes geotechnical investigation cost (3%)

## 3.7 DEEP WELL SYSTEM

### 3.7.1 Definition

Deep wells, aside from going deeper, are typically drilled and cased, in contrast to shallower, driven well points. The deep well systems considered in this section are designated to dewater soil at greater depths, to extract leachate or to intercept flow of ground-water upgradient of a site.

### 3.7.2 Units of Measurement

Costs are given in terms of dollars per well. Cost per well per foot may also be useful but available cost estimates assume the similar depths.

### 3.7.3. Summary Data

3.7.3.1 Expenditures

No expenditure data was available at this time.

3.7.3.2 Estimates

Cost estimate ranged from
$4,862/well
to (both wells were at 46 feet deep)
$13,513/well

It should be noted (see Table 20) that 62% of the low estimate and 85% of the high estimate were for (1) a geotechnical investigation, (2) an overhead allowance (25%); and (3) a contingency allowance (30%). On the above range of cost, a cost-per-foot-per-well basis would be $106-295/foot/well.

### 3.7.4 Factors Found to Affect Costs

#### 3.7.4.1 Expenditures

No expenditure data are available at this time.

#### 3.7.4.2 Estimates

The following factor affected the cost estimates:

- Well depth
- Well diameter
- Pumping capacity
- Related costs:
    - geotechnical investigation
    - overhead allowance
    - contingency allowance

Variations in depth of well are not quantified in the data, but costs of drilling wells typically vary with depth. Variations in diameters of wells are also not given in the data, and therefore are not quantifiable, but costs for wells of larger diameter are generally proportionally higher because of increases in costs of labor, equipment and material. The effects of pumping capacity on capital expenditures are difficult to quantify because of the importance of site-specific hydrogeology to well yield (e.g., increasing the pump size, and hence cost, may have no effect on well yield if the well does not recharge quickly enough to justify the larger pump). Any consideration of cost functions for pumping capacity must regard hydrogeology, pump capacity and well design. Costs of electricity for pumping comprised about 5-10% of the costs of operation and maintenance. Hence, this component of cost, which varies directly with pumping capacity has a relatively small effect on total O&M costs compared to the other cost items of operation and maintenance such as sampling and analysis.

Related costs had the greatest discernible effect on cost estimates since they comprise the majority of both estimates. Table 19 shows the proportion of total capital cost involved in these related components for estimates given in Table 20.

## TABLE 19
## COMPONENT COSTS OF DEEP WELL ESTIMATES

| Estimate source | Geotechnical Investigation | Overhead Allowance | Contingency Allowance | Total |
|---|---|---|---|---|
| SCS "Impoundment" | 30% | 25% | 30% | 85% |
| SCS "Landfill" | 7% | 25% | 30% | 62% |

The reason for the significantly higher proportional and absolute cost estimate for the smaller impoundment (1.16 acres, 5 wells) compared to the landfill (13.4 acres, 13 wells) is unclear.

Estimated Sources

- SCS 1980

# TABLE 20
## DEEP WELL COST ESTIMATES

### (1982 Dollars)

| Data Source | Depth, diameter, # wells | Pumping | Operation & Maintenance | Capital Cost |
|---|---|---|---|---|
| US EPA<br>SCS<br>"Impoundment"<br>1980 | 46 feet deep<br>6 inches pvc<br>5 wells | submersible pumps 574 foot header to 3'deep discharge trench | $9,110-9,920/ year | $7,443 - $13,513/well<br>(1) |
| US EPA<br>SCS<br>"Landfill"<br>1980 | 46 feet deep<br>6 inches pvc<br>13 wells | submersible pumps. 1 hp, 984 foot header to gravel filled discharge trench | $9,830-<br>$10,640/year | $4,862 - $7,976/well<br>(2) |
| | | | | |
| | | | | |

(1) Includes geotechnical investigation (30%) overhead (25%) and contingency (30%) allowance.

(2) Includes geotechnical investigation (7%), overhead (25%) and contingency (30%) allowance.

## 3.8 EXTRACTION/INJECTION WELL SYSTEM

### 3.8.1 Definition

Extraction/injection wells are usually well points, which are driven into the ground, or they are occasionally deep wells, which are drilled and cased. A series of extraction and injection wells (well points or cased, drilled wells) is given as the basis of design from which to compare costs. Costs for water treatment are not included. The system used as a basis of design is sometimes referred to as a leachate recirculation or plume containment system. In addition to decontamination of ground-water, this system may be used to control migration of leachate.

### 3.8.2 Units of Measurement

Total capital costs are given instead of unit costs for two reasons. First, unlike most other remedial technologies, extraction/injection systems are composed of several components that are not readily interchanged since they act as a unit. Extraction, injection and monitoring wells all comprise roughly equal parts of the system. Capacity in terms of gallons-per-minute was not used because of its dependence on hydrogeology, and this information was not usually available.

### 3.8.3 Summary Data

#### 3.8.3.1 Expenditure

No expenditure data was available at this time.

#### 3.8.3.2 Estimates

A range of estimates cannot be given since the units of the two estimates were not comparable (see Table 21).

# TABLE 21

## EXTRACTION/INJECTION WELL COST ESTIMATES

### (1982 Dollars)

| Data Source | Extraction | Injection | Pumping | Operation & Maintenance | Total Capital |
|---|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | 7, six inch well, 35 feet deep<br>pvc casing | 7, six inch wells (+ four back up wells<br>pvc casing | 4 inch submersible pumps<br>8 inch transfer pipe, 1,000 feet | Not given | $321,432 |
| US EPA<br>Radian<br>1983 | 10, six inch wells (1)<br>average depth 50 feet | six inch wells | submersible pumps<br>50 gpm per well | $70.88/Mgd<br>electricity and monitoring | Not given (2)<br>("$37.50/vertical foot") |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

(1) Based on "50 gpm per well, 500 gpm/site".

(2) Assuming 20 wells, 50 feet deep, total capital cost = $37,500

### 3.8.4 Factors Found to Affect Costs

3.8.4.1 Expenditure

No expenditure information is available at this time.

3.8.4.2 Estimates

The following factors contributed to the cost estimates of the extraction/injection well systems:

- number of wells
- depth of wells
- diameter of wells
- casing
- submersible pump capacity
- transfer pipe length and diameter

The paucity of data precludes quantification of the effects of these factors.

Estimate Sources

- U.S. EPA, JRB-RAM, 1980
- U.S. EPA, Radian, 1983

## 3.9 EXTRACTION WELLS/SEEPAGE BASINS

### 3.9.1 Definition

A series of extraction wells is used to collect ground-water, and a seepage basin/trench or recharge basin is used to recharge the ground-water. This system, as with the extraction/injection well system above, may have a treatment system placed in-line, or it may be used simply to control flow of leachate. Costs of treatment are not considered in this section. Seepage basins are often used in permeable soil, such as the glacial till, where injection wells are not needed for infiltration.

### 3.9.2 Units of Measurement

Total capital cost is given instead of unit costs because, unlike most other remedial technologies, extraction well/seepage basins are composed of several components that are not readily interchanged since they act as a unit. Extraction and monitoring wells, trench/basin size and pumping/transfer equipment all comprise roughly equal parts of the system. Capacity in terms of gallons-per-minute was not used because of its dependence on hydrogeology.

### 3.9.3 Summary Data

### 3.9.3 Expenditures

The one expenditure found was:

| | |
|---|---|
| Total capital | $31,269 (9.5 gpm total extraction, two 100-foot long seepage trenches) |
| Operation and maintenance | $27,500/year |

The expenditure was for two extraction trench wells (one 80 x 10 x 4 feet, another 4 x 10 x 16 feet) and two recharge trenches (100 x 4 x 10 feet).

### 3.9.3.2 Estimates

The range given in the one available source of estimate was:

| | |
|---|---|
| Total capital: | $33,618 - 53,360 |
| Operation and Maintenance: | $10,856 - 11,812/year |

This is actually from a single source that predicts a range of costs in the U.S.

## 3.9.4 Factors Found to Affect Costs

### 3.9.4.1 Expenditures

The following factors affected expenditures:

- Number of wells
- Size of wells
- Depth of wells
- Pumping capacity
- Seepage basin design

Because of inadequate data and the lack of a similiar site, comparison of these factors is not possible (see Table 22). However, it should be noted that many of the factors affecting expenditures are similar to those affecting the subsurface drain, especially the design of the extraction well trench using stone of decreasing size toward the inside of the trench. This increased capital expenditures, but probably decreased costs of operation and maintenance.

### 3.9.4.2 Estimates

The following factors affected cost estimates:

- Overhead allowance
- Contingency allowance
- Well size and number
- Pumping capacity

## TABLE 22

## EXTRACTION WELLS/SEEPAGE BASIN EXPENDITURES

(1982 Dollars)

| Data Source | Extraction (trench-well) | Seepage basin | Pumping | Operation & Maintenance | Total Capital |
|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1982<br>New Jersey | A. 80x4x10 feet-12 inches (1)<br>B. 16x4x10 feet-8 inches pvc<br>TOTAL: 143 cuyd | two trenches:<br>100x4x10 feet (2)<br>TOTAL: 296 cuyd | 9.5 gpm<br>submersible pump | $27,500 (3) | $ 31,269<br>($71/cuyd) |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

(1) Dual media, stone/pebble, filter. Well slotted 2.5 feet.

(2) Plywood shoring construction

(3) Conservatively assumed to be 1/3 of water biotreatment operation & maintenance

The overhead and contingency allowance comprised 25% and 20%, respectively, of the total estimated capital cost. Size and number of wells would be expected to be proportional to the cost, but quantification is not possible without other estimates for comparison (see Table 23). Pumping capacity would also be expected to be proportional to cost, but hydrogeological factors affect this on a site-specific basis.

### Expenditure Sources

- ELI/JRB Case Studies, 1983

### Estimates Sources

- SCS, 1980

## TABLE 23

## EXTRACTION WELLS/SEEPAGE BASIN COST ESTIMATES

(1982 Dollars)

| Data Source | Extraction | Injection | Pumping | Operation & Maintenance | Total Capital |
|---|---|---|---|---|---|
| US EPA<br>SCS - "Leachate Recirculation-Landfill"<br>1980 | six deep wells<br>46 feet deep<br>(drilled, cased) | 2,067 x 2x3 feet<br>6 inch cement pipe, perforated<br>3/4 inch gravel | six submersible pumps | $9,200-10,010/year<br>$10,856-$11,812/year | $33,618-$53,360 (1) |
| | | | | | |
| | | | | | |
| | | | | | |

(1) Includes 25% overhead and 20% contingency allowance

## 3.10 SUBSURFACE DRAIN

### 3.10.1 Definition

A subsurface drain is basically an underground, gravel-filled trench designed to intercept and transport leachate or infiltrating water away from the waste site. Often, perforated pipe or tile is laid along the trench bottom, draining to a collection sump or tank. The sides and bottom of the trench may be lined with plastic or clay before the trench is backfilled with gravel.

### 3.10.2 Units of Measurement

The unit costs for subsurface drains are given in dollars-per-unit-length for three ranges of trench depth because facilitates quick cost estimates from a single trench dimension. Depth of trench was found to be the greatest single factor affecting costs. The ranges in depth given in the Summary section 3.10.3.1 were determined by the aggregation found for the costs of the different trenches. Variations may have been caused by technical factors discussed in section 3.10.4, such as type of excavator used and sheet piling required.

### 3.10.3 Summary Statistics

#### 3.10.3.1 Expenditures

The expenditures for subsurface drains in three groups of depth ranges were:

| Cost per Unit Length | Depth |
|---|---|
| $24/LF | 3 feet |
| X = $370/LF (SE=$208/LF, n=4) | 8.5-14.5 feet |
| $1,733/LF | 22.5 feet |

The 2 subsurface drains at the high end of the range involved significant marginal costs for false-starts, delays, and overdesigning. The lowest cost drain was shallow enough that it did not require sheet piling or wooden shoring during construction. Costs of operation and maintenance involve sampling and replacement costs. Drains typically remain unclogged for 10-20 years, but site conditions and design of drains affects this operational period. Costs of operation and maintenance accounted for separately, where they were encountered.

### 3.10.3.2 Estimates

Estimates of cost for subsurface drains ranged from:

Capital:

$1.94/LF

to

$218/LF

Operation and maintenance:

$10,337/year

to

$11,293/year

The range of estimates spanning two orders of magnitude resulted from ancillary costs and variations of depth. The plan for the most costly drain included the cost for a geotechnical investigation, which accounted for 50% of the estimated cost. The least costly hypothetical drain was installed 1-2 feet deep. Costs of operation and maintenance were frequently noted but not consistently quantified.

## 3.10.4 Factors Found to Affect Costs

### 3.10.4.1 Expenditures

The following factors were found to affect the costs of subsurface drains shown in Table 24.

1. contaminated soil removal
2. trench length and depth
3. plumbing complexity
4. gravel installation
5. storage tank or sump size

Contaminated soil, which may require secure disposal, may be encountered while constructing the trench or the sump. Excavation of contaminated soil, which resulted in additional costs for disposal, occurred when trenches were constructed within a contaminated area, rather than at the site perimeter. This additional cost was incurred at the ELI/JRB Wisconsin site #1 where hexavalent chromium-contaminated soil was disposed of from the hole excavated for a sump. The PCB-contaminated soil at the ELI/JRB California site #1, however, was returned to the cap because the system was considered an "Immediate Remedial Measure", not a long term remedy. This provision eliminated the cost of off-site disposal of the PCB-contaminated soil.

The importance of the trench length and depth is discussed above in connection with unit costs. The size of trench depended on factors such as type of waste, permeability of soil, climate and purpose of the system. A relatively large, three-armed drainage system was used at the most costly site, ELI/JRB California site #1, because of the compact soil and the strong adhesion of the PCBs to the soil, and because of the seasonally heavy rains in the Mediterranean climate. The length of the drain at the ELI/JRB Michigan site reflected its purpose of relieving hydraulic pressure on the asphalt emulsion cut-off wall. The purpose of the relatively small drain at trench A of the ELI/JRB New Jersey site, was to collect contaminated water by creating a cone of depression of the water table. The size of the drains affected costs of construction by dictating different installation methods between the deepest and the shallowest drains. Steel sheet piling was driven into place to support the 30 foot (10 m) deep trenches

# TABLE 24
# SUBSURFACE DRAIN EXPENDITURES

(1982 Dollars

| Data Source | Length x trench (filter) depth | Width | Sump depth, etc. | Operation and maintenance | Unit cost-capital |
|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1981<br>Wisconsin #2 | 240 feet<br>x<br>12 ( ) feet | 4 feet | 15 feet | $648/year<br>(a)<br>72,000 gal. | $36/LF |
| US EPA<br>ELI/JRB<br>1982<br>Wisconsin #1 | 750 feet<br>x<br>3 ( 1/3) feet | 2 feet | 2 sumps:<br>4 feet<br>6 feet | not given | $24/LF |

during construction, at the ELI/JRB California site # 1; whereas no reinforcement was necessary at Site 5. The cost of shoring was perhaps the most important factor in the costs of drains for the deeper drains at the ELI/JRB California sites #1 and 2, which used steel sheet piling and the New Jersey site, which used plywood shoring. The available data on costs are inadequate to quantify this relationship, but the difference in costs among those shown in Table 24 suggests its significance.

Both depth of trenches and the depth of filters varied among the sites. The depth of the filter affects the required amount of stone or gravel fill. The complexity of plumbing of the collection pipe running the length of the trench ranged from a single pipe to multi-level pipes. A single pipe ran the length of the trench at most of the case study sites, and either drained into a collection sump or was drained by an extraction pump, as in the case of the New Jersey site. Three levels of slotted PVC piping were installed in each of three trench arms at the ELI/JRB California Site #1. Each level had valves to control the flow from the different oil-lense depths into the sump. The cost for design, materials and installation of the trench plumbing at the California Site #1, was significantly higher than that in other case study sites.

The procedure for installation of gravel fill affected the costs of the drain at one site where a different design was used. The New Jersey site involved an outer layer of 1/4-inch (0.6 cm) washed stone which was placed around an inner layer of 1 1/2-inch (3.2 cm) stone, which surrounded the collection pipe. The purpose of this relatively complex design was to provide filtration by the outer layer and high collection rates from the coarser inner layer. This added expense was intended to obviate the need for future operation and maintenance costs for clearing the clogged pipe. Reconstruction of a drain installed in 1976 that had become clogged was necessary at the Michigan site. Drains at the other case study sites used a single size of stone or gravel.

The second item of cost included in the costs of the subsurface drains is for storage of collected water in sumps or tanks. The New Jersey site was the only site for which costs of leachate storage were not included because the collected water was pumped directly into the treatment system. The inclusion of sumps in the other site estimates was based on the assumption that the size and cost of sumps and storage tanks were generally proportional to the size of the collection trench. The storage systems differed in types as well as size. Large prefabricated concrete sumps were used at the end of some drains, whereas steel tanks or pipes were used at others.

### 3.10.4.2 Estimates

The following factors affected the estimates of subsurface drain cost shown in Table 25.

- trench (filter) depth and length
- storage tank or sump size and type
- related costs

Trench and filter depth and length affected drain estimates in a manner similar to that described in the expenditure section above. However, technical details (such as the gravel size, thickness, and permeability of the filter and backfill) were often not available for consideration.

The SCS estimates were significantly affected by the inclusion of related costs such as:

- geotechnical investigation
- overhead allowance
- contingency allowance

The cost of the geotechnical investigation was included only in the estimate for "Impoundment" drain. This element comprised 50% of the total cost of the drain. Overhead (25%) and contingency (25%) allowances were added to both the "Impoundment" and "Landfill" estimates. The variations in the estimated costs of subsurface drains from JRB and SCS were caused by a combination of two factors. First, the JRB estimates used unit costs at the high end of the range used by SCS. Second, the JRB estimates included three components not included in the SCS estimates. However, since these items were responsible for only $24.70 of the $694/LF difference (11%) in total unit cost between JRB and SCS, their influence was relatively insignificant. The influence of component unit costs that were included was therefore more significant than the influence of component costs that were not included in the JRB estimates.

## TABLE 25
## SUBSURFACE DRAIN COST ESTIMATES

(1982 Dollars)

| Data Source | Length x trench (filter) depth | Width | Sump depth, etc. | Operation and maintenance | Unit Cost |
|---|---|---|---|---|---|
| US EPA<br>SCS<br>"Impoundment"<br>1980 | 197 feet<br>x<br>16(4) feet (1) | 3.3 feet | sump depth not given<br>cement pipe in drain | $10,337-<br>$11,293/year<br>50 gpm . | $113 - 218/LF (2) |
| US EPA<br>SCS<br>"Landfill"<br>1980 | 835 feet<br>x<br>20(13) feet (1) | 3.3 feet | depth not given<br>4 inch cement pipe in drain | $10,337-<br>$11,293/year<br>50 gpm. | $26 - 38/LF |
| US EPA<br>Radian<br>1982 | 1,000 feet<br>x<br>20(10) feet (1) | 4 feet | sump depth not given<br>perforated pvc in drain | $70.88/<br>Mgd<br>50 gpm | $28/LF |
| US EPA<br>JRB-RAM<br>1980 | 3,300 feet (3)<br>x<br>20(2) feet (1) | 4 feet | 4 manholes;<br>2 wet wells;<br>15 lateral drains (20' each) | not given<br>2 x 25 gpm | $15/LF |

(1) Trench (filter) depth shows excavated volume vs of gravel installed, respectively

(2) Includes geotechnical investigation (50%)

(3) Includes laterals

## TABLE 25
## SUBSURFACE DRAIN COST ESTIMATES (continued)

(1982 Dollars)

| Data Source | Length x trench (filter) depth | Width | Sump depth, etc. | Operation and maintenance | Unit Cost |
|---|---|---|---|---|---|
| US EPA<br>$CH_2$ M Hill<br>Feasibility Study 1983 | 3,250 feet<br>x<br>15 (?) feet | not given | not given | not available | $5.50/LF |
| US EPA<br>Feasibility Study 1981<br>New Jersey | 2,495 feet<br>x<br>1-2 (?) feet | not given | 4" slotted | not available | $1.94/LF |
| US EPA/NYS DEC<br>$CH_2$ M Hill<br>Bids 1982<br>New York | 3,250 feet<br>x<br>15(?) feet | not given | not given | not available | $12/LF<br>$11.70/LF<br>$ 7/LF<br>$ 5/LF<br>$ 4/LF |

## Expenditure Sources

- ELI/JRB Case Studies, 1983

## Estimated Sources

- JRB - RAM, 1980
- Radian, 1983
- US EPA OERR contractor bids
- SCS 1980

# 4.0 AQUEOUS AND SOLIDS TREATMENT

## 4.1 ACTIVATED SLUDGE

### 4.1.1 Definition

This treatment technology involves introducing organic-laden wastewater into a reactor where an aerobic bacterial culture is maintained in suspension (mixed liquor). The bacteria respire a moeity of the organic materials to form carbon dioxide, water, and metabolic byproducts and assimilate another fraction to form more cells. Oxygen is supplied to the reactor by mechanical or diffused aeration with air or an oxygen-enriched gas stream. Intimate contact between wastewater, sludge, and oxygen is maintained in a properly operating reactor. A portion of the mixed liquor is continuously passed to a settling tank (clarifier) where sludge (primarily bacterial cells) is separated from wastewater. A portion of the settled sludge is returned to the reactor to maintain the proper balance of microorganisms, while the remainder is removed from the system. Typical equipment includes aeration tanks and basins, clarifiers, compressors, aerators (diffused or mechanical), and recycle pumps and plumbing.

### 4.1.2 Unit of Measurement

Costs are given in terms of dollars per gallon treated. Estimates from one source were available only in terms of cost-per-pound of Biochemical Oxygen Demand (BOD) reduction. Also, where available, assumptions of the volumetric capacity of a system are given, but cost-per-unit estimates of reduction of mixed organic contaminants were not calculable.

### 4.1.3. Summary Data

#### 4.1.3.1 Expenditures

The following expenditure was found:

| | |
|---|---|
| Capital: | $6.3 million/Mgd ($87,514/13,680 gpd) |
| Operation & Maintenance: | $0.0165/gal. |

This system was a nutrient-enhanced biodegradation system, constructed with retrofitted 5,400-gallon milk trailers for aeration and settling tanks. It was not a standard engineer designed and activated sludge system, though the cost components were very similar. The cost of operation and maintenance includes a relatively small expenditure for nutrient salts ($19.20/day; $0.0014/gallon; 8%). The use of previously used or salvaged material generally produced significant savings in costs over the expected cost for new materials.

#### 4.1.3.2 Estimates

Cost estimates ranged from:

| | |
|---|---|
| Capital: | $200,000/Mgd<br>to<br>$390,000/Mgd |
| Operation & Maintenance: | $18,000/Mgd/year<br>to<br>$25,000/Mgd. |

The compilation of these estimates is unclear from the available data.

### 4.1.4 Factors Found to Affect Costs

#### 4.1.4.1 Expenditures

The following factors were found to contribute to expenditures:

- Materials (used and salvaged)
- In- house design and maintenance
- In-house power and process steam
- System flexibility (access holes)

Although no expenditure data for a system constructed of new components is available for comparison, the cost of this system given in Table 26 may have been significantly lower than that of a system using new equipment and contractor labor. One cost item that increased the capital expenditure, possibly unnecessarily, was the construction of a roller mount and access ports for the pipe air spargers. This part of the system was intended to allow the spargers to be cleaned of biomass buildup without sending a technician into the tank. This maintenance has not been necessary in over 2 years of operating the system (as of August 1983).

#### 4.1.4.2 Estimates

The lack of technical detail about the hypothetical systems for which estimates were given precludes consideration of specific factors affecting the costs (see Table 27).

Expenditure Sources

- ELI/JRB Case Studies, 1983

Estimates Sources

- Radian, 1983
- SCS, 1981

# TABLE 26
# ACTIVATED SLUDGE EXPENDITURES

## (1982 Dollars)

| Data Source | Capacity; rate | Aeration | Design | Operation & Maintenance | Direct Capital |
|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1982<br>New Jersey | 0.014 Mgd (1) | 20 cfm through stone pipe diffusers | retrofitted milk trailers used for aeration tanks | $2.89/Mgd(2)<br>$226/day<br>$0.0165/gal. | $6.3 million/Mgd<br>($87,514) |
| | | | | | |
| | | | | | |
| | | | | | |

(1) Million gallons per day

## TABLE 27

## ACTIVATED SLUDGE COST ESTIMATES

**(1982 Dollars)**

| Data Source | Capacity; rate | Aeration | Design | Operation & Maintenance | Direct Capital |
|---|---|---|---|---|---|
| US EPA<br>Radian<br>"Conventional"<br>1983 | 1.0 Mgd (1)<br>5.0 Mgd<br>10.0 Mgd | 1.1 lb $O_2$/lb $BOD_5$ removed | 40 year service life<br>detention time 6 hours | \$25,000/Mgd<br>\$24,000/Mgd<br>\$18,000/Mgd | \$390,000/Mgd<br>\$250,000/Mgd<br>\$200,000/Mgd |
| US EPA<br>SCS<br>February 1981<br>1980 | 7.2 Mgd (1)<br>(5,000 gpm) | Not given | 10 year service life | \$358,720/Mgd (2)<br>\$709,180/Mgd | |
| | | | | | |
| | | | | | |

(1) Million gallons per day
(2) First year O&M.

## 4.2 AEROBIC, ANAEROBIC, AND FACULTATIVE LAGOONS

### 4.2.1 Definition

Aerobic, anaerobic and facultative lagoons are large, earthen impoundments designed for microbial degradation of organic wastes. They may be used as detached, individual treatment devices or, more commonly, in combination with other in-line treatment systems.

Aerated lagoons are 6 to 20 feet deep. Aeration devices supply supplemental oxygen and partial mixing. A sludge blanket accumulates on the bottom and undergoes anaerobic decomposition. A non-aerated cell (clarifier) usually follows to allow solids to settle before discharge of the supernatant effluent.

Anaerobic lagoons are deep (20 feet). High organic loadings and a gas impervious layer of grease on the surface promote thermophilic anaerobic digestion. Wastewater enters near the bottom and exits below the surface. Excess sludge is washed out with effluent; waste recirculation is unnecessary.

Facultative lagoons are 3 to 8 feet deep basins in which wastewater is allowed to stratify into aerobic, intermediate, and anaerobic zones. Stratification is enhanced by settling solids, water temperature and density variations. Oxygen in the surface layer is provided by diffusion of air across the air-water interface and by photosynthesis. Mechanical aeration devices are not used to introduce oxygen to facultative lagoons.

### 4.2.2 Units of Measurement

Costs are given in dollars-per-million gallons-per-day treated. This cost basis assumes similarly effective treatment, as well as extrapolative total costs.

### 4.2.3 Summary Data

#### 4.2.3.1 Expenditures

No actual expenditure data are available at this time.

#### 4.2.3.2 Estimates

Cost estimates ranged from

| | | |
|---|---|---|
| Capital: | $0.08 million/Mgd | (7.2 Mgd) |
| | to | |
| | $3.4 million/Mgd | (0.14 Mgd) |
| Operation & Maintenance: | $0.005 million/Mgd | (10 Mgd) |
| | to | |
| | $1.23 million/Mgd | (0.14 Mgd) |

The estimates reflect widely varying scales of operational assumptions. Large (5-10 Mgd) scale scenarios were at the bottom of the range of unit cost estimates, while smaller operations (under one Mgd) had generally higher estimates. The lower estimates excluded certain related components such as land, pumping and liners.

### 4.2.4 Factors Found to Affect Costs

#### 4.2.4.1 Expenditures

No actual expenditure data are available at this time.

### 4.2.4.2 Estimates

The following factors appeared to significantly affect the cost estimates:

- Scale of operation
  - land, pumping, liner containers and overhead
- Effectiveness of Treatment
- Extent of Aeration
- Climate

The estimates were significantly related to the scale of operation, as noted in section 4.2.3.2. This effect results partly from the economies of scale inherent in larger operations, but it also reflects the different nature of general construction estimating manuals (see Table 28).

The large hypothetical systems estimated by Radian excluded the costs of pumping as well as costs of liners and land. These systems were similar in design to those that would be part of a sewage or industrial treatment plant. A contingency and engineering cost of 30% was included in the New Hampshire Feasibility Study estimate. The inclusion of this cost in the other estimates is unclear from the available data.

The estimates include a variety of levels of contaminant removal. These levels were generally given in terms of BOD or COD. These may not provide accurate estimates of removal effectiveness for many refractory or highly toxic organics but they provide useful standards for comparison. In cases where removal efficiency information was available, no relationship with total unit costs was apparent. However, for similarly designed systems, effectiveness of removal would probably be proportional to cost.

## TABLE 28

## ANAEROBIC, AEROBIC AND FACULTATIVE LAGOONS

### (1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance(1) | Capital |
|---|---|---|---|---|
| US EPA<br>OERR 1982<br>Feasibility Study<br>New Hampshire | AEROBIC<br>28 day detention period<br>4 cells, 12 feet deep<br>3,500 CFM aeration | 144,000 gpd (0.14 Mgd)(2) | $1.23 million/ Mgd | $3.4 million/Mgd |
| US EPA<br>Radian<br>1983 | AEROBIC<br>7 day detention time<br>88% BOD/COD removal<br>10 feet deep<br>30 year service life | 1 Mgd | $0.03 million/ Mgd | $0.03 million/Mgd |
| | | 10 Mgd | $0.07 million/ Mgd | $0.02 million/Mgd |
| US EPA<br>Radian<br>1983 | ANAEROBIC<br>gravity flow, excludes land, pumping, liner<br>60% BOD removal<br>50 year service life | 1 Mgd | $0.0125 million/Mgd | $0.5 million/Mgd |
| | | 10 Mgd | $0.005 million Mgd | $0.3 million/Mgd |
| US EPA<br>Radian<br>(coll climate)<br>1983 | FACULTATIVE<br>gravity flow; excludes land, pumping and liner<br>20 lb BOD5/acre/day<br>80% BOD/COD removal | 1 Mgd | $0.015 million/Mgd | $1.5 million/Mgd |
| | | 10 Mgd | $0.006 million/Mgd | $0.7 million/Mgd |

(1) Annual
(2) Million gallons per dav

## TABLE 28

## ANAEROBIC, AEROBIC AND FACULTATIVE LAGOONS (continued)

(1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance(1) | Capital |
|---|---|---|---|---|
| US EPA<br>Radian<br>(warm climate)<br>1983 | FACULTATIVE<br>gravity flow; excludes land, pumping and liner.<br>40 lb $BOD_5$/acre/day<br>80% BOD/COD removal | 1 Mgd<br>10 Mgd | $0.015 million/Mgd(22)<br>$0.006 million/Mgd | $0.65 million/Mgd<br>$0.35 million/Mgd |
| US EPA<br>SCS<br>1981<br>( mid-1978 dollars ) | AEROBIC<br>70% removal<br>100 ppm BOD | 7.2 Mgd | $0.03 million/Mgd | $0.08 million/Mgd |
| | | | | |
| | | | | |

(1) Annual (2) Million gallons per day (3) First year cost

The extent of aeration varied among the treatment systems. The cost of aeration equipment, in terms of both capital, and operation and maintenance costs, may be significant. This difference in design and cost also significantly alters performance. For example, the hypothetical aerobic system had a presumed efficiency of 88%; whereas the anaerobic system achieved only 60%. This difference suggests the need to quantify costs in terms of dollars per unit of contaminant removed per unit of time when comparing systems for the same waste stream. The climate affects system performance of facultative systems and hence, it affects costs. The facultative system in a warm climate was more efficient than the cooler climate system.

Estimates Sources

- Radian, 1983
- SCS, 1983

## 4.3 ROTATING BIOLOGICAL CONTACTORS

### 4.3.1 Definition

This system is a form of fixed-film biological treatment. A slime layer of microorganisms grows attached to polystyrene or polyvinyl chloride disks 6 to 12 feet in diameter. The disks are mounted vertically on a horizontal axis of rotation in treatment tanks. Rotation of the disks exposes the slime surfaces alternately to oxygen in the atmosphere and organic matter in the wastewater. Both oxygen and organic matter are metabolized, the organic material is assimilated as microbial mass or degraded to form carbon dioxide, water and other metabolic byproducts by aerobic microorganisms. The rotation mixes and aerates the contents of the tank and causes excess slime layers to be sloughed off as growth continues. Sloughed slime is subsequently separated from the supernatant in a settling system. A complete RBC system usually consists of two or more trains of disks with each train consisting of several stages.

### 4.3.2 Units of Measurement

Costs are given in terms of dollars-per-million-gallons-per-day treated, when available, for comparison with other water treatment technologies.

### 4.3.3 Summary Data

4.3.3.1 Expenditures

No actual expenditure data are available at this time.

4.3.3.2 Estimates

The range of cost estimates was:

Capital: $0.9 million/Mgd (10 Mgd)
to
$29.6 million/Mgd (0.144 Mgd)

| | | |
|---|---|---|
| Operation & Maintenance: | $22,500/Mgd/year | (10 Mgd) |
| | to | |
| | $4.6 million/Mgd/year | (0.05 Mgd) |

The range of estimates reflects a widely varying scale of operation assumed for the four estimates from two sources. The high estimate is derived from dividing the total (capital or O&M) by the treatment rate, in million gallons per day. This method of scaling up the estimates of smaller system may result in the multiplication of some fixed costs. The low estimates are derived from estimates for very large scale sewage treatment systems. The actual costs can be derived by multiplying the unit cost by the treatment rate.

### 4.3.4 Factors Found to Affect Cost

#### 4.3.4.1 Expenditures

No actual expenditure data are available at this time.

#### 4.3.4.2 Estimates

The following factors appeared to have significant effects on cost estimates.

- Scale of treatment
- Inclusion of related costs
    - overhead allowance
    - contingency allowance
    - settling tanks, etc.

The scale of treatment operation appeared to significantly affect costs (see Table 29). The estimate may for this reason, be of limited comparability since the Radian estimate is for a very large system, compatible with flow rates at a municipal sewage treatment system, or large industrial waste plant.

## TABLE 29

## ROTATING BIOLOGICAL CONTRACTOR COST ESTIMATES

**(1982 Dollars)**

| Data Source | Design basis | Capacity | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>OERR<br>1982<br>New Hampshire | for volatiles removal; follows neutr. and ppt. includes nutrient salt mixing tanks, clarifier, dewatering, sludge recycle | 0.05 Mgd | $4.6 million/Mgd | $29.6 million/Mgd (2) |
| | | 0.144 Mgd | $3.9 million/Mgd | $23 million/Mgd |
| US EPA<br>Radian<br>1983 | 100,000 sq ft of media per shaft<br>80-90% BOD removal<br>99% ammonia removal<br>cost excludes 1° and 2° clarifiers | 1 Mgd (1) | $32,500/Mgd | $0.9 million/Mgd |
| | | 10 Mgd | $22,500/Mgd | $0.9 million/Mgd |
| | | | | |
| | | | | |

(1) Million gallons per day.

(2) Includes engineering & contingency (30%), and contractor's overhead (25%).

(3) Annual

The effect of inclusion of related costs on the estimates is unclear. The New Hampshire Feasibility Study assumed an additional 30% for contractor overhead. It is unclear whether these costs are included in the Radian estimate.

The exclusion of certain systemic components from the Radian estimate may have produced an underestimation of the costs, compared to those given in the feasibility study. The Radian estimate included only those particular components used for the rotating biological contactor and excluded settling tanks, clarifiers and chemical mixing units. Generally, the Radian estimate gave information on a unit which is to be retrofitted to a primary treatment plant.

Estimates Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

## 4.4 AIR STRIPPING

### 4.4.1 Definition

The air stripping process enhances volatilization of volatile organic compounds (VOC) by increasing the air-liquid interfactial surface area and the velocity of the air passing over it. Towers and basins have both been used; however, only towers are considered here. The typical tower is similar in construction and configuration to a water cooling tower. Contaminated water enters near the top of the tower and flows through a distribution plate and then downward over the packing, which may consist of plastic beads, saddles or piping. A blower forces air in at the lower sides and bottom of the tower and forces it past the water and packing, and then out through the top. Stripped water is collected at the bottom of the tower, and exits into the distribution system (or as effluent). Basins, which consist of a temporary swimming pool with a series of spray nozzles across them have been used for leachate stripping, but no costs were available for them at this time (August 1983).

### 4.4.2 Units of Measurement

Costs are given in dollars per million gallons per day for ready comparison with other water treatment technologies.

### 4.4.3 Summary Data

#### 4.4.3.1 Expenditures

The one source of actual expenditure data indicated the following costs.

| | |
|---|---|
| Capital: | $182,540/Mgd (million gallons per day) |
| Operation & Maintenance: | $9,921 - 11,905/Mgd |

No comparison with other site data is possible at this time since this is the only actual expenditure information available (August 1983). This expenditure was significantly lower than those estimated with engineering/construction costing manuals.

### 4.4.3.2 Estimates

The following range of estimates for air stripping systems was found:

| | | |
|---|---|---|
| Capital: | $607,000/Mgd | (1.44 Mgd) |
| | to | |
| | $7.3 million/Mgd | (0.0504 Mgd) |
| Operation & Maintenance: | $89,000/Mgd | (1.44 Mgd) |
| | to | |
| | $3.2 million/Mgd | (0.0504 Mgd) |

The range given is for two out of the three estimates that were available. The third estimate is not shown in the above range because the estimate reflects only shipping and set-up costs for a borrowed tower, and not construction costs. The above range seems to reflect the economies of scale for varying size systems. The less costly system on a unit rate basis ($607,000/Mgd capital; $89,000 O&M) was the larger (1.44 Mgd); while the more costly system ($7.3 million/Mgd capital; $3.2 million/Mgd) was the smaller system (0.0504 Mgd). Therefore, in absolute terms the smaller the system, the higher the cost.

## 4.4.4. Factors Found to Affect Costs

### 4.4.4.1 Expenditures

The following factors appeared to affect the costs:

- Capacity (VOC reduction and flow rate)
- Blower size

The relationship of the cost and the capacity of the system considered was nearly linear (see Table 30). It was stated in the Feasibility Study that the cost would increase about the same amount for each of the five towers added. The VOC reduction was expected to be related to costs, but no quantitative comparison is possible without more expenditure data. The blower size significantly affected the operation and maintenance (O&M) since most O&M cost was involved in electrical power for the fans. The O&M expenditure was relatively low since power costs in the northwest U.S. were unusually low during the estimation period.

### 4.4.4.2 Estimates

The following factors seemed to affect the cost estimates

- Capacity contaminant (reduction and flow rate)
- Blower size
- Included costs
- Packing material

Estimates of cost varied directly according to rate of flow of the untreated influent (see Table 31). This variability was reflected in increased size of towers, volumes of packing and capacities of pumps. Varying economies of scale seemed to be the most significant factor affecting costs. The least costly system on a cost-per-unit treated-per day basis ($607,000/Mgd capital; $89,000 O&M) was the largest (1.44 Mgd); while the most costly system ($7.3 million/Mgd caital; $3.2 million/Mgd O&M) was the smallest system (0.0504 Mgd). Hence, in absolute terms the smallest system was the least costly, but on relative cost-per-million-gallons-per-day basis, the economies of scale gave a unit cost advantage to the larger system.

## TABLE 30
## AIR STRIPPING EXPENDITURES

(1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance (1) | Capital |
|---|---|---|---|---|
| US EPA<br>OERR<br>$CH_2$ M Hill<br>Washington<br>1983 | Five towers:<br>12 feet dia. x<br>30 feet high;<br>60 hp blower;<br>29,000 cfm/tower | 5.04 Mgd<br>(3,500 gpm)<br>95% removal | \$9,921-<br>11,905/Mgd<br>(2) | \$182,540/Mgd |
| | | | | |
| | | | | |
| | | | | |

(1) Annual cost

(2) Estimated, actual expenditures not yet encountered (8/83)

## TABLE 31
## AIR STRIPPING COST ESTIMATES

### (1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance (1) | Capital |
|---|---|---|---|---|
| US EPA<br>OERR - Weston<br>Feasibility Study<br>1982<br>New Hampshire | 23 foot high tower<br>two 600 cfm blowers<br>5 hp motors<br>15 psig steam boiler | 0.0504 Mgd (35 gpm)<br>0.144 Mgd (100 gpm) | \$3.2 million/Mgd<br>\$2.3 million/Mgd | \$7.3 million/Mgd<br>\$3.9 million/Mgd |
| US EPA<br>Radian<br>1983 | 20 foot high tower;<br>sch 80 pvc pipe packing, cross-stack;<br>400 cuft/gallon | 0.144 Mgd<br>1.44 Mgd<br>80% removal | \$286,000/Mgd<br>\$89,000/Mgd | \$1.07 million/Mgd<br>\$607,000/Mgd |
| US EPA<br>OERR-CH$_2$ M Hill<br>Feasibility Study<br>1983<br>Minnesota | one tower;<br>12 feet dia. x 300 feet 30 feet high;<br>barrowed from other site; shipping/set up only | average:<br>1 Mgd.<br>maximum:<br>2.16 Mgd.<br>95% removal | \$60,765/Mgd<br>\$28,131/Mgd | \$124,610/Mgd (2)<br>\$57,690 |
| | | | | |

(1) Annual cost

(2) "Capital" costs include only shipping of treatment tower from Tacoma, Washington, and set up costs (pad, appurtenances, etc.)

The effectiveness of reduction of the contamination in the various systems was reflected in the costs. Since a variety of factors affect removal efficiency, it is difficult to relate these many factors to costs. These factors include, but are not limited to: pumping rate, climate, and air flow rate and packing type.

Increased pumping rates may increase the total amount removed, but decrease the percentage removed and, in combination with the increase in electrical costs caused by higher pumping rates, produce both a less efficient system and a less cost-effective system. Climatic effects are primarily related to ambient temperature; increases in temperature produce a higher volatilization of contaminants. Correlated to this phenomenon are the costs of heating the influent stream to offset seasonal cooling or increase efficiency. Air flow rate, which affects stripping efficiency, is a function of the size and speed of operation of blowers, each of which affect both capital and O&M costs.

Packing types also varied among the estimates and had some, unquantified effect on efficiency and costs. The proportion of costs devoted to tower packing is unclear but the costs of different packing materials of varying effectiveness were given in one estimate. ($15/cu.ft. - $95/cu.ft.). Therefore, an optimization is necessary when choosing a packing type in order to acheive a given level of removal with a certain system size.

The variation in included costs is especially noteworthy for the system estimated in the Minnesota Feasibility Study. This cost estimate did not include tower construction, but rather only included the shipping and erection of a tower borrowed from the Tacoma, Washington site. Although this system was estimated for a four month operation (while an alternate water system was to be installed), the cost given are trebled for annualized comparison. All of the estimates given include engineering overhead, at about 25 - 30%.

Expenditure Sources

- State and Federal Superfund work

Estimates Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

## 4.5 CARBON TREATMENT

### 4.5.1 Definition

Carbon treatment systems generally filter contaminated water through a bed of granular activated carbon, which selectively adsorbs organic compounds with physical and/or chemical action. When the carbon in the filter reaches breakthrough, that is, when the rate of desorption, equals the rate of adsorption, the carbon is replaced, and the old carbon is disposed, destroyed, or regenerated with heat or solvents. Carbon adsorption is often used in combination with other treatment technologies such as aeration, filtration and flocculation.

### 4.5.2 Units of Measurement

Costs are given in dollars per million gallons per day, when available. Where no rate information was available, costs are given in dollars per gallon.

### 4.5.3 Summary Data

4.5.3.1 Expenditures

Costs for carbon treatment were found to range from:

$ 0.10/gallon
to
$ 0.40/gallon

These costs included system rental, carbon, transportation, and labor to erect systems and other equipment. The higher cost system includes a greater accounting of all of these related costs, while the lower cost system was operated for a short period and did not include carbon disposal or regenerations costs.

### 4.5.3.2 Estimates

The cost estimates range from:

| | | |
|---|---|---|
| Capital: | $643,000/Mgd | (complete construction cost) |
| | to | |
| | $14,132/Mgd | (erection of leased system) |
| Operation and Maintenance: | $11,786/Mgd/year | |
| | to | |
| | $1.5 million/Mgd/year | |

The wide range of cost estimates reflects a variety of included costs. The lowest cost system does not include the entire cost of purchased materials, but rather the costs of rental and erection of the system. The highest estimated cost includes complete costs of materials and construction.

## 4.5.4 Factors Found to Affect Costs

### 4.5.4.1 Expenditures

The following factors affected the expenditures for carbon filtration:

- Inclusion of pretreatment costs
- Rental/purchase expenditure

Costs of pretreatment are included in the cost given for the carbon treatment system for both expenditures detailed in Table 32. Although these costs for pretreatment may have been necessary for efficient carbon use, and may comprise a minority of the component costs, it is important to note that they were included. The higher cost system included a clarifier for removal of suspended solids from the influent, and an air stripping system for preliminary removal of of methylene chloride from the waste stream. The waste stream of this system was subsequently filtered through the four cascade carbon towers. The lower cost system included only pea-gravel and lime for precipitating and filtering out solids.

# TABLE 32

# CARBON TREATMENT EXPENDITURES

## (1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>ELI-JRB<br>1980<br>New Jersey | clarification<br>air stripping<br>four cascade<br>carbon filter | 0.25 Mgd<br>25-150 gpm | $0.30 - 0.47/gallon (1) | |
| US EPA<br>ELI-JRB<br>1979<br>Missouri | pre-gravel/<br>lime prefilter;<br>three stage carbon<br>2,400 lb carbon | Not given | $0.13 - 0.23/gallon (1) | |
| | | | | |
| | | | | |

(1) Rented system and related costs.

Both expenditures given are for leased systems. The costs generally included transporting the filter units, erection, and operating labor.

### 4.5.4.2 Estimates

The following factors affected the cost estimates.

- Size
- Inclusion of related costs
    - rental/construction
    - carbon regeneration
    - additional prefiltering or treatment

The total system cost estimates varied directly with size (see Table 33). The cost-per-million-gallons-treated-per-day was relatively more constant, though it varied over one order of magnitude for capital costs, and three orders of magnitude for costs of operation and maintenance (O&M). No economies of scale were apparent since, even from the same data source, cost-per-million-gallons-treated-per-day of larger systems was sometimes higher than for smaller systems.

Renting a system appeared to be less costly than most construction scenarios in two instances. Quotes for leased systems were obtained from vendors for the feasibility studies at the Illinois and Minnesota sites. Costs included set-up and operation labor, materials and equipment. It is unclear whether regeneration costs were included in most examples. It is presumably included in rented costs of rented systems if a carbon change was not necessary during the lease period, such as in the Minnesota scenario.

Costs for additional prefiltering and treatment, aside from carbon, were included only in two estimates. In the second highest systemic estimate (the New Jersey feasibility study), the costs of sulfur dioxide gas treatment to precipitate out iron, airstripping to remove volatile organics, and neutralization to stabilize the pH were

# TABLE 33
# CARBON TREATMENT COST ESTIMATES

(1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>Radian | 30 min. contact time; | 0.14 Mgd<br>(100 gpm) | $357,000/Mgd | $143,000/Mgd |
| 1983 | 1 lb per 5,000 gal;<br>off-site regeneration | 1.4 Mgd<br>(1,000 gpm) | $250,000/Mgd | $643,000/Mgd |
| US EPA/NJDEP<br>CDM<br>Feasibility Study (F.S)<br>1983 | $SO_2$ for Fe ppt.<br>air stripping<br>neutralization (3)<br>1 lb per 1,000 gall. | 2 Mgd<br>(1,389 gpm) | $1.5 million/ Mgd | $473,500/Mgd |
| New Jersey | | 7 Mgd<br>(4861 gpm) | $1.3 million/ Mgd | $471,429/Mgd (4)<br>$138,000/Mgd (5) |
| US EPA<br>$CH_2$ M Hill<br>(vendor quote for F.S.) | sand filters<br>carbon tanks<br>rented system | 0.28 Mgd<br>(200 gpm) | $11,786/Mgd<br>(2) | $346,429/Mgd (1) |
| 1983<br>Illinois | | 2.16 Mgd<br>(1,500 gpm) | $222,000/Mgd | $476,852/Mgd |
| US EPA<br>SCS 1981<br>(mid 1978 dollars) | pressurized<br>pretreated<br>in situ regeneration | 7.2 Mgd<br>(5,000 gpm) | $883,200 | $234,600 |

(1) Includes set-up and breakdown of all major equipment, piping, controls, utility, erection, transportation, carbon and sand. No purchase.

(2) System rental

(3) All costs included

(4) First 5 years

(5) After 5 years.

### TABLE 33

### CARBON TREATMENT COST ESTIMATES (continued)

(1982 Dollars)

| Data Source | Design | Capacity | Operation & Maintenance | Capital |
|---|---|---|---|---|
| U.S. EPA<br>$CH_2$ M Hill<br>Feasibility Study<br>1983<br>Minnesota | pressurized system<br>13 min. contact time<br>80,000 lb carbon | 2.16 Mgd<br>(1,500 gpm) | $82,000/Mgd | $14,132/Mgd (1) |
| | | | | |
| | | | | |
| | | | | |

(1) Includes set-up and breakdown of all major equipment, pippin, controls, utility, erection, transportation, carbon and sand. Not purchase.

included. The costs of neutralization and clarification were included in the SCS II estimate. The costs of chemicals and power comprised 90% of the O&M costs for this system.

## Expenditure Sources

- ELI/JRB Case Studies, 1983

## Estimated Sources

- Radian, 1983
- US EPA OERR contractor Feasibility Studies

## 4.6 OIL/WATER SEPARATOR

### 4.6.1 Definition

An oil/water separator skims oil off of water by taking advantage of the immiscibility of these liquids. The two general types of oil/water separators are (1) a floating skimmer-type, and (2) a tank-type, coalescing plate separator. Costs are given in this section for the second type. This type, which is typically larger, uses a series of horizontal and vertical hydrophilic and hydrophobic plates to enhance oil globule flotation. These systems may be used in series with each other and with other treatment technologies, which may provide "polishing" to remove residual low level contaminants.

### 4.6.2 Units of Measurement

Costs are given in dollars-per-million-gallons treated-per-day when data availability make it possible.

### 4.6.3 Summary Data

4.6.3.1 Expenditure

The one expenditure available was:

| | | |
|---|---|---|
| Capital: | $289,200 | (includes hookup and controls) |
| Operation and Maintenance: | $50,000/year | (capacity unknown) |
| | $2.70-4.16/gallon | (1,000-1,500 gallons/month) |

The cost-per-gallon is relatively high because of the low rate of treatment.

### 4.6.3.2 Estimates

The single estimate available was:

| | | |
|---|---|---|
| Capital: | $91,587 | 5,000 gpm capacity |
| | $12,720/Mgd | (7.2 Mgd) |
| Operation and Maintenance: | $267,456/1st year<br>($0.0001/gallon) | |

The assumptions for this system suggest that it is intended as an auxiliary to a larger treatment system. Appurtenances and control costs are not included as they are for the above expenditure. This causes an underestimate for the capital cost because of the excluded costs and a low estimate for the O&M because the maximum capacity flow rate was assumed for deriving the unit cost.

## 4.6.4. Factors Found to Affect Costs

### 4.6.4.1 Expenditures

The following factors affected estimates:

- Flow rate (utilization of capacity)
- Inclusion of related costs:
    - appurtenances
    - controls
    - tank housing

Flow rate was probably the most important factor affecting the expenditure (see Table 34). The combination of a locally tight soil with a high organic content, and the natural adhesion of oil to such highly organic soil resulted in a very low flow rate of only 1,000-1,500 gallons per month for the California case study site. The effect on operation and maintenance unit costs by flow rate is even more clear. The relatively low flow rate divided into the annual operation and maintenance costs results in a relatively high unit O&M cost.

The expenditure data included a variety of related costs that may not be accounted for in estimates or other expenditures. They include upgrading of appurtenances to connect the lines for the treated effluent to the local POTW, a building to enclose the storage tanks, and a control system for operating the separator. These related fixed costs may be spread among other systemic components for a larger system in which the oil/water separator is a minor component, such as in a large POTW or complex industrial waste (pre)treatment operation.

#### 4.6.4.2 Estimates

The following factors affected the estimate (Table 35):

- System capacity
- Related costs

The estimate of unit costs includes only costs of basic materials and assumes a capacity flow rate. Therefore, it was probably an underestimate of unit costs of an installed system to the extent that the actual flow rate is generally less than capacity.

Since this hypothetical system appears to be designed as an auxiliary to a large POTW or an industrial (pre)treatment system certain related fixed costs may be excluded or spread among the larger system components. The flow rate variations may overestimate the actual contaminant removal range because the bulk of the flow through an oil/water separator is water rather than oily contaminant. Therefore, estimates may be made more accurate by calculating the cost per volume of contaminant removed. However, the cost of removal of contaminants is very difficult to measure because of the

## TABLE 34

## OIL/WATER SEPARATOR EXPENDITURES

(1982 Dollars)

| Data Source | Design, capacity | Contaminant | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1983 California | Coalescing plate separator<br>capacity unknown<br>1,000-1,500gallons/month | PCB/oil, 10 c oil in water from french drain sump | $50,000/year ($2.70-$4.16/gallon) | $289,200 |
| | | | | |
| | | | | |
| | | | | |

## TABLE 35
## OIL/WATER SEPARATOR COST ESTIMATES

**(1982 Dollars)**

| Data Source | Design, capacity | Contaminant | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>SCS<br>1981<br>(1978 Dollars) | Coalescing plate separator<br>maximum 5,000 gpm (7.2 Mgd) | Not given | 1st year =<br>$267,456 ($0.0001/ gallon) | $91,587 ($12,720/Mgd)<br>(simple average cost = $1.98/1,000 gallons) |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

variations in contaminants and removal efficiencies. The removal efficiency of an oil/water separator is affected primarily by oil drop size; retention time, density differences between the aqueous and the organic phases, and the temperature.

### Expenditure Sources

- ELI/JRB Case Studies, 1983

### Estimate Source

- US EPA, SCS, 1981

# 5.0 GAS MIGRATION CONTROL

## 5.1 PIPE VENTS

### 5.1.1 Definition

Pipe vents are vertical or lateral perforated pipe installed in, through or around the landfill for controlling gases. They are usually installed at a landfill perimeter on 30 to 60 foot centers and extend down to the water table or the landfill base, sometimes in combination with trench vents for the control of lateral gas migration. Pipe vents are usually surrounded by a layer of coarse gravel to prevent clogging by solids or water. They may discharge passively to the atmosphere or be connected to a negative pressure collection system for possible treatment.

### 5.1.2 Unit of Measurement

Unit cost is given in dollars-per-pipe vent. Other units such as depth and diameter are used to describe each pipe vent.

### 5.1.3 Summary Data

5.1.3.1 Expenditures

No actual expenditure data are available at this time.

5.1.3.2 Estimates

The estimates ranged from:

$445 (6 feet deep)
to
$1,310 (30 feet deep)

No information was available about the assumptions for the lowest estimate. But the highest (capital) estimate included additional items such as PVC casing and a blower fan, which was not included in the lower estimates.

### 5.1.4 Factors Found to Affect Costs

#### 5.1.4.1 Expenditure

No actual expenditure data are available at this time.

#### 5.1.4.2 Estimates

The following factors affected the cost estimates for pipe vents:

- Depth
- Pipe diameter
- Casing
- Ventilation fan size

The factors affecting cost estimates are very similar to those affecting well points, deep wells and monitoring well costs, since construction elements are similar. Well costs are typically proportional to their depth. Costs also increase with pipe diameter because of increases in costs of materials, installation, labor and equipment. Some estimates for some components were given in terms of dollars-per-inch diameter-per-foot depth, indicating diameter (in inches) and depth (in feet) affect cost proportionately.

Casing (pvc) was included in the JRB and Radian cost estimates, but not the more shallow New Jersey Feasibility Study estimates (see Table 36). This element added $4.50 to 6.50/LF for 4 - and 6 - inch casings, respectively.

The fan affects both capital and operation and maintenance costs. The fan size, and its capital cost estimate when given was identical. The reason for the differing operation and maintenance cost from these sources is unclear.

Estimates Sources

- JRB-RAM, 1980
- Radian, 1983
- US EPA OERR contractor Feasibility Studies
- US EPA OERR contractor bids

## TABLE 36
## PIPE VENT COST ESTIMATES

**(1982 Dollars)**

| Data Source | Depth | Diameter | Ventilation | Operation & Maintenance | Capital Unit Cost |
|---|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | 30 feet; incl.<br>mushroom cap | pipe: 4 inches<br>pvc casing: 6 inches | one fan/pipe- 0-136 cfm @ 3 inches $H_2O$ | \$18/year | \$1310each |
| US EPA<br>Radian<br>1983 | 30 feet; incl.<br>mushroom cap | pipe: 3 inches<br>pvc casing: 4 inches | one fan/pipe- 0-136 cfm @ 3 inches $H_2O$ | \$85/year | \$975 each |
| US EPA-NH State<br>$CH_2M$ Hill<br>Bids 1982<br>New Hampshire | Not given | Not given | Not given | Not given | \$520 each<br>\$500 "<br>\$500 " |
| US EPA<br>$CH_2M$ Hill<br>RI/FS 1983<br>New Jersey | 6 feet<br>90° elbow + T | 4 inch<br>pvc, sch 40 | none | none given | \$445 each |

(1) Includes 800 LF of vent piping; + 10% contingency

## 5.2 TRENCH VENTS

### 5.2.1 Definition

Trench vents are deep, narrow trenches backfilled with gravel, forming a path of least resistance through which gases migrate upward to the atmosphere or to a collection manifold. They are typically constructed around the perimeter of a waste area, or across a section of the site to form a barrier against lateral migration of methane or toxic vapors. Trenches can be open, or capped with clay and fitted with collection laterals and riser pipes, venting to the atmosphere or connecting to a negative pressure fan or blower.

### 5.2.2 Unit of Measurement

Unit cost is given in terms of dollars-per-linear foot because it reflects the functional value of mitigating gas migration across an area.

### 5.2.3 Summary Data

5.2.3.1 Expenditures

No actual expenditure data are available at this time.

5.2.3.2 Estimates

The cost estimates for trench vents ranged from:

$35/LF (20 feet deep)
to
$646/LF (20 feet deep)

The highest estimate included significant costs for sheet piling, geotextile trench lining and well-point dewatering of the excavated trench, none of which were included in any of the other three estimates. The lowest estimate was for a simple passive trench vent with no piping or ventilation.

## 5.2.4 Factors to Affect Costs

### 5.2.4.1 Expenditures

No expenditure data are available at this time.

### 5.2.4.2 Estimates

The following factors were found to affect the trench vent estimates:

- Trench size
- Pipe vent size
- Ventilation for size
- Inclusion of related costs:
    sheet piling
    geotextile lining
    overhead allowances
    contingency allowances
    well point dewatering

Trench depth seemed to have the most significant effect on costs (see Table 37). The 20-foot depth scenario used for the JRB-RAM estimate required sheet piling, which, despite reuse assumptions, comprised 81% of the total capital cost. Also, well-point dewatering (14% of total capital cost) was considered necessary for this deep trench vent.

Pipe vents, added to the trench vent designs, varied among the estimates given. The pipe vents for the highest and lowest estimates were not detailed in the design plans. However, the length of laterals and risers for the two SCS "Landfill" estimates was identical; only the pipe diameter varied. This did not appear to significantly affect the costs.

## TABLE 37
## TRENCH VENT COST ESTIMATESA

(1982 Dollars)

| Data Source | Trench Size | Pipe vents | Ventilation fan | Operation & Maintenance | Capital unit cost |
|---|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | 500 feet (1)<br>x<br>20 feet (d)<br>x<br>4 feet (w) | laterals and risers= 500 feet | none | not given | $646/LF (1) |
| US EPA<br>SCS-active control<br>"Landfill"<br>1980 | 3,068 feet (1)<br>x<br>12 feet (d)<br>x<br>4 feet (w) | risers- 951 feet x 4 inches<br>laterals - 3,068 feet x 8 inches | 2 hp<br>1,250 cfm | $7,015 - $13,777/year | $41 - 63/LF |
| US EPA<br>SCS-gravel trench vent<br>"Landfill"<br>1980 | 3,068 feet (1)<br>x<br>12 feet (d)<br>x<br>4 feet (w) | risers- 951 feet x 6 inches<br>laterals-3,068 feet x 12 inch | none | $897 - $1,888/year | $40 - 87/LF |
| US EPA<br>SCS-gravel trench vent<br>"Landfill"<br>1980 | 3,068 feet (1)<br>x<br>20 feet (d)<br>x<br>4 feet (w) | none | none | $130 - $283/year | $35 - [illegible]2/LF |

(1) Includes sheet piling construction and geotextile lining

The operation and maintenance costs were significantly higher (by an order of magnitude) for the estimate which included a ventilation fan. This increased cost was presumably to cover additional electricity and maintenance. The cost of synthetic trench lining (12% of total capital costs) was included only in the JRB-RAM estimate, which assumed \$2.38/sq ft for hypalon.

The SCS estimates included allowances for overhead and contingencies as follows:

| Estimate Scenario | Overhead | Contingency |
|---|---|---|
| Active control | 25% | 30% |
| Passive control | 25% | 20% |
| Gravel trench | 25% | 15% |

## Estimates Sources

- JRB-RAM, 1980
- SCS, 1980

## 5.3 GAS BARRIERS

### 5.3.1 Definition

A synthetic membrane can be used in combination with other technologies to form a barrier against horizontal or vertical gas migration. Clay or concrete slurry walls and grout curtains may also perform a similar function, but at a higher cost; these technologies are usually reserved for barriers to migration of ground-water. Synthetic membranes may be installed during construction of a trench vent or a subsurface drain, each of which involve digging a trench. The cost of the trench and other tasks may be derived from the section on that technology. Similar information on barriers to vertical migration may be taken from the surface sealing section. Considering costs of materials, synthetic membranes may need to be doubled or layers of sand may need to be included to prevent punctures from gravel and stones. Also, an additional several feet should be allowed for the membrane at the top of the trench to allow for proper anchoring. Trench bottoms should also be lined.

### 5.3.2 Unit of Measurement

Costs are given in terms of dollars per square foot because it best expresses the functional value of gas barriers.

### 5.3.3 Summary Data

#### 5.3.3.1 Expenditures

No expenditure data are available at this time.

5.3.3.2 Estimates

The cost estimates ranged from:

| | | |
|---|---|---|
| Capital | $0.39/sq.ft. | asphaltic concrete |
| | to | |
| | $3.00/sq.f.t | hypalon (36 mil) |
| Operation and Maintenance | $900/year | (24 four hour inspections/year) |

The information source does not explicitly state whether both installation and material costs are included in these estimates.

### 5.3.4 Factors Found to Affect Costs

5.3.4.1 Expenditure

No expenditure data are available at this time.

5.3.4.2 Estimates

The following factor primarily affected gas barrier cost estimates:

- Installation
- Material type
- Material amount

The inclusion of installation costs is the most important factor affecting these cost estimates. Although the references for estimates drew data from the same sources, Table 38 shows that there are significant differences that may have been caused by the inclusion or exclusion of installation costs.

## TABLE 38
## GAS BARRIERS COST ESTIMATES

(1982 Dollars)

| Barrier Material | Design assumptions | JRB - RAM,1980 | Radian,1983 | Operation & Maintenance(1) |
|---|---|---|---|---|
| Synthetic liners: | | | | $900 - 1,062/year |
| Hypalon | 36 mil thickness | $0.71-0.77/ sq.ft. | $2.40-3/sq ft | |
| Teflon | 10 mil thickness | $2.62/sq.ft. | $2.22/sq ft | |
| Geotextile backing | heavy weight,2 layers | $1.77-2.36/ sq.ft. | $1.50-2/sq ft | |
| Gunite | 4 inch, layer with wire mesh | $5.45-$9.91/ sq.ft. | $5.50-10.30/ sq ft | |
| Asphaltic concrete | 4-6 inch layer including base | $0.39-0.66/ sq.ft. | $0.33-0.56/ sq ft | |
| Clay | Material cost, hauling, backfill by dozer, vibratory compaction every 6 inches for trench vent only. | $0.51/cu.ft. | $0.43/cu ft | |

(1) Operation and maintenance cost estimated by Radian only

The types and amount of materials affected cost estimates, but the data were inadequate to quantify these effects.

Estimates Sources

- JRB-RAM, 1980
- Radian, 1983

## 5.4 CARBON ADSORPTION (GAS)

### 5.4.1 Definition

Carbon filters are added to vents to collect gaseous contaminants (typically volatile organics) from the vent gases. Large gas filtration systems (10,000 and 100,000 cfm - roughly 1,000 cu.ft. of carbon) used in manufacturing processes are available, but this section includes information on relatively small systems (7 cu. ft. of carbon) for passive venting systems.

### 5.4.2 Units of Measurement

Costs are given in terms of dollars per filter. Units such as volume of air filtered or amount of contaminant collected are important for describing a given filter unit, when available.

### 5.4.3 Summary Data

5.4.3.1 Expenditures

One expenditure for carbon gas filtration was available:

$188/filter

This cost does not include the cost of the used 55 - gallon drums that were retrofitted, or the cost of labor to fill these drums with carbon. Only the cost of materials for the granular activated carbon is included. Each of four improvised filters was saddled over the vents of 5,400 gallon activation and settling tanks used to biodegrade butanol and acetone from contaminated ground-water.

Operation and maintenance costs include carbon testing and regeneration/replacement costs.

### 5.4.3.2 Estimates

One estimate was available from price quote sheets (this may be considered similar to expenditures except that no record of an expenditure is available).

$635/Ventsorb (for orders of 1-3)

Ventsorb is a commercial carbon filter, very similar to the improvised filter for which costs are given above. Related costs of construction (drum cutting, filling, painting) are included in the delivered cost.

### 5.4.4 Factors Found to Affect Costs

The following factors affected the cost of the carbon vent adsorber (see Tables 39 and 40):

- Size
- Related costs
- Flow rate

Cost increases due to increases in the size of the filters were correlated only to the amount of activated carbon filler used, since the drums used were reconditioned waste barrels. Any containment structure would affect costs at a relatively small incremental proportion of the cost, since the cost of carbon (roughly $1.00/lb) is more significant.

The vent filters were mounted on the cylindrical tanks using wooden pallets, and in-house labor was used to retrofit and fill the drum canisters. The cost of these related components would be expected to increase the cost of a factory-built carbon filter, as noted below.

## TABLE 39
## GAS TREATMENT EXPENDITURES

(1982 Dollars

| Data Source | Filter Size | Contaminant | Operation & Maintenance | Total Cost |
|---|---|---|---|---|
| US EPA<br>ELI - JRB<br>New Jersey 1982 | 55 gallon drum (1) | butanol<br>acetone | not available | $188/each (2) |
| | | | | |
| | | | | |
| | | | | |

(1) Retrofitted use drum

(2) Includes carbon cost only

# TABLE 40
# GAS TREATMENT COST ESTIMATES

**(1982 Dollars)**

| Data Source | Filter Size | Contaminant | Operation & Maintenance | Total Cost |
|---|---|---|---|---|
| Industry vender quote (1983) | 55 gallon drum | not given | not given<br>varies with contaminant concentration | $635 each |
| | | | | |
| | | | | |
| | | | | |

The air flow rate affects costs in general, because of the specific costs of a fan and the higher rate of adsorption. The fan would not only add to the capital cost, but would add to the operation and maintenance costs in two important ways: First, the fan itself would require electricity and maintenance to keep running. Second, the higher rate of adsorption would increase the frequency of replacement for the filter. The paucity and similarity of available data obviates contrast of factors between sources. However, the following brief listing of factors is appropriate:

- Filter size
- Flow rate (use of ventilation fan)
- Contaminant concentration

Flow rate is probably the most important independent factor of the above factors.

Neither of the passive-type vent filters for which costs are given above included costs for a fan, which would significantly increase costs of operation and maintenance. JRB Remedial Action Manual (Rogoshewski, et al., 1980) included the relationship shown in Figure 1. The hypothetical system for which these costs were estimated is a large carbon filtration unit, several orders of magnitude larger than the ventsorbs noted above.

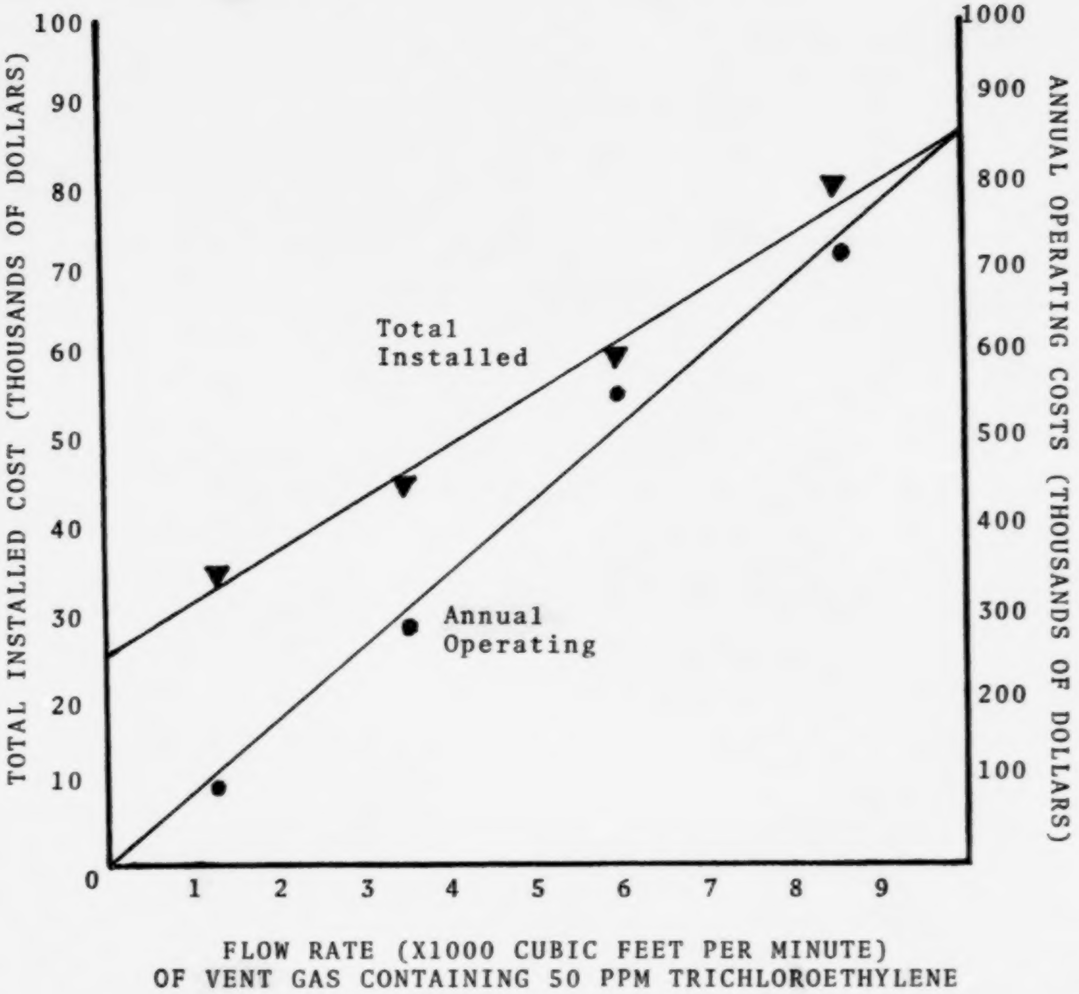
## Expenditure Sources

- ELI/JRB Case Studies, 1983

## Estimates Sources

- US EPA OERR contractor bids

### Figure 1. CAPITAL AND OPERATING COSTS FOR NONREGENERATIVE CARBON GAS VENT FILTER



SOURCE: CALGON, 1980

## 6.0 MATERIAL REMOVAL

## 6.1 EXCAVATION/REMOVAL TRANSPORTATION AND DISPOSAL/TREATMENT

### 6.1.1 Definition

Excavation, transportation and disposal costs are grouped here because, (1) similar factors are involved in all three tasks, and (2) some actual expenditure data are available only in terms of the three aggregated tasks. Excavation refers to the work necessary to remove and load the hazardous material, ready for transport from its found position. (This may involve significant digging and waste classification, or only surface scraping.) Transportation involves hauling loaded materials off-site to a disposal/treatment facility. Disposal/treatment may include landfilling, incineration or treatment.

### 6.1.2 Units of Measurement

Costs are given in dollars per cubic yard (cy) because it serves as a standard soil excavation measure. A cubic yard is assumed to weigh one ton, which is a common assumption at landfills. Disposal and transportation costs in several cases are given in terms of dollars/ton because haulers and landfills used weight measures.

### 6.1.3 Summary Statistics

6.1.3.1 Expenditures

The following ranges of excavation/removal, transportation and disposal/treatment expenditures were found:

| | |
|---|---|
| Excavation/Removal: | $15 - $460/cuyd |
| Transportation: | $29 - $145/cuyd |
| Disposal Treatment: | $17 - $356/cuyd |

These cost elements cannot necessarily be summed, since the extremes of the ranges are derived from different sources with different scenarios and assumptions. The sum of the three unit operations from the highest and lowest cost sites, results in the following site total

Excavation, Transportation and Disposal :
$4.70 - $884/cuyd

The lowest cost site (Texas-$6.06/cuyd) required only pumping a liquid into a tank truck for removal, while the highest cost site reflected the use of boats and level A protective gear to retrieve floating pails from a canal. The salient reasons for the low cost of transportation at the lowest cost site were unclear, but at the highest cost site (Massachusetts -$145/cuyd), a relatively high demurrage (compensation for delay) was charged because of sample analysis delays. The disposal/treatment costs varied greatly with the waste compatibility. The lowest disposal cost (New York City - $17/cuyd) was charged for oil heavily contaminated with highly volatile solvents, which facilitated incineration. The highest disposal cost (Florida - $356/cuyd) was for disposal of extremely caustic "super tropical bleach" (calcium oxide-chlorinated lime), which required treatment and neutralization prior to disposal. Costs of operation and maintenance may involve monitoring of ground-water or site inspections or implementation security measures to prevent illegal dumping, which is often repeated at former sites. These costs were accounted for separately when they were encountered.

### 6.3.1.2 Estimates

The following ranges of cost estimates for excavation/removal, transportation, and disposal/treatment were found:

| | |
|---|---|
| Excavation/removal: | $0.85 - 4.09/cuyd |
| Transportation: | $1.67 - 94.40/cuyd |
| Disposal/treatment: | $ 12 - 283.20/cuyd |
| Site Total: | $ 379 - 434/cuyd |

The lowest estimates (SCS "impoundment" - $0.85 - 1.27/cuyd) required use of a front-end loader for excavation/removal, whereas the highest estimate (SCS "landfill" - $3.42-4.09/cuyd) required an excavator for deeper excavation. The low transportation estimate was extrapolated from a construction-engineering manual, whereas the high estimate reflected actual bids from different types of hauling firms. Disposal costs varied from $12/cu.yd. at a sanitary landfill, to $283.20/cu.yd. for contaminated sediment at an engineered landfill.

No operation and maintenance costs were assumed for the excavation/removal, transportation and disposal/treatment cost estimates.

### 6.1.4 Factors Found to Affect Costs

#### 6.1.4.1 Expenditures

The following technical factors were found to affect the costs of excavation/removal, transportation and disposal/treatment:

Excavation or On-site Transfer:

1. Excavation depth
2. Site surface characteristics
3. Health and Safety requirements
4. Material - liquid/solid/drums
5. Waste quantity

Transportation:

1. Distance to disposal facility
2. Accessibility to road
3. Material - liquid vs. solid
4. Waste quantity

Disposal:

1. PCB Waste
    - (a) Concentration-over/under 500 ppm
    - (b) Material-solid vs. liquid

2. Non-PCB RCRA Hazardous Waste
    - (a) Solid vs. liquid
    - (b) Aqueous vs. organic

In addition, the following primary non-technical factors affected costs:

A. Community relations
B. Interstate relations
C. Inflation and regulatory factors.

The effect of excavated depth on the costs shown in Tables 41 and 42 is probably non-linear, since the most significant changes in cost resulted from differences in equipment. For example, the depth of excavation at the Case Study sites in Idaho, New Jersey and Massachussetts #1 necessitated the use of a Caterpillar 235, which is a large, treaded backhoe, with a 30 foot (10 m) arm, which rents for about $70/hour without crew. A smaller, less expensive backhoe such as a Case 580C was used at other sites where the excavation depth was shallower. A front loader, which is generally even less expensive, was used at sites where only surface scraping was performed.

Excavation was performed at a relatively quicker pace, which reduced labor and rental costs, at sites with sandy and unconsolidated soil. No excavation costs were incurred at the New York City #1 and California #2 Case Study Sites, because removal involved pumping liquid waste into trucks from tanks and ponds, respectively. Surface characteristics of the site probably had a relatively small effect on the costs of excavation at most of the case study sites. The waste was excavated from a steep embankment at Case Study Massachussetts #1. Clean fill was removed from the top of the embankment to prevent its cross-contamination with the wastes that were buried at the toe of the slope during the excavation. This process added a small amount to the labor and rental charges.

## TABLE 41
## EXCAVATION EXPENDITURES

(1982 Dollars)

| Data Source | Length x trench (filter) depth | Width | Sump depth, etc. | Operation and maintenance | Unit Cost-capital |
|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1981<br>California #1 | 210 feet (a)<br>x<br>22.5 (21.5) feet | 3 feet | 29.5 feet<br>triple level drain pipes | $54,000/<br>year (b)<br>(1,000-1,500) gallons | $1,733/LF |
| US EPA<br>ELI/JRB<br>1980<br>California #2 | 261 feet<br>x<br>14.5 (10) feet | 4-6 feet | 20 feet<br>+ bucket well | $307/year<br>excludes treatment<br>(10 mil. gallon) | $936/LF |
| US EPA<br>ELI/JRB<br>1981<br>New Jersey | 280 feet (c)<br>x<br>10(6) feet | 4 feet | no sump<br>pea gravel around pipe;<br>gravel jacket | $89,640<br>year (b)<br>(19 mil.gal.) | $424/LF |
| US EPA<br>ELI/JRB<br>1980<br>Michigan | 990 feet<br>x<br>8.5(6) feet | not given | rebuilt drain (d) | not given | $85/LF (d) |

(a) Three drain arms summed; slotted pvc piping stacked 3 feet apart
(b) Includes water treatment O&M
(c) Three trenches summed: 2 injection, 1 withdrawal
(d) Includes original and renovation costs

## TABLE 41
## EXCAVATION EXPENDITURES (continued)

(1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation Removal | Trans. (Distance) | Disposal Treatment(1 | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA<br>OERR<br>1982<br>Florida | liquid;<br>5 gal. pails | 18.7 cuyd;<br>757 pails | Ca oxide<br>chlorinated lime | surface | $460/cuyd | $0.17/cuyd/ mi.<br>(2 trucks)<br>$68/cuyd (4) | $356/cuyd | $18,155 (2,4)<br>$884/cuyd |
| US EPA<br>ELI/JRB<br>1981<br>Calif. | bottles,<br>pellets | 430 cuyd | pesticides<br>(DBCP, etc.) | 15 feet | $158/cuyd | $119/cuyd<br>(140 miles) | | $276/cuyd |
| US EPA<br>ELI/JRB<br>1981<br>Mass. | soil<br>sludge | 1,052 cuyd and<br>151 drums (3) | chlorinated solvents | 3-15 feet | $ 51/cuyd | $145/ton<br>(513 mi.) | $90/ton | $285/ton |
| US EPA<br>ELI/JRB<br>1981<br>Idaho | soil<br>sludge | 817 cuyd | pesticides<br>solvents | 13 feet | $207/cuyd<br>(254 mi.) | | | $207/cuyd |

(1) Landfilled unless other wise noted
(2) Total cost includes other tasks
(3) 615 cuyd disposed; cuyd:ton ratio used by contractor= 1:1.3; 276 cuyd aerated on-site
(4) If 400 miles assumed

## TABLE 41
## EXCAVATION EXPENDITURES (continued)

(1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1 | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA ELI/JRB<br>Mass. 1981 | drums<br>soil | 481 cuyd | solvents | surface | Not Available | $77/cuyd<br>(480 miles) | $91/ton | -- |
| US EPA ELI/JRB 1979<br>Missouri | soil | 2,635cuyd | pentachlorophenol | surface | $39-87/ cuyd | $29/cuyd<br>(170 miles) | $61/ton | $110-159/cuyd |
| US EPA ELI/JRB 1978<br>Conn. | drums<br>soil | 4,770 cuyd | solvents<br>metals | 3-13 feet | $15/cuyd | $92/ton<br>(497 mi.) | $55/ton | $164/ton |
| US EPA ELI/JRB 1982<br>NYC | oil | 229 cuyd | solvents | surface | Not Available | $89/ton<br>(818 mi.) | $17/cuyd (2) | -- |

(1) Landfilled unless otherwise noted (2) Incineration

## TABLE 41

## EXCAVATION EXPENDITURES (continued)

(1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1) | Total |
|---|---|---|---|---|---|---|---|---|
| U.S. EPA<br>OERR<br>1982<br>Indiana | liquids<br>sludges | 2,500 gal.<br>27 cuyd.<br>Tot.=55 cuyd | solvents<br>still bottoms<br>adhesives<br>metals<br>PCB (4) | surface | $89/cuyd | Not Available | $28/cuyd (2)<br>(landfill, recycle) | $10,362 (3) |
| U.S. EPA<br>1982<br>OERR<br>Texas | liquid | 99,000 gallons | xylene | surface | $0.03/gal.<br>vacuum truck | Not Available | Not Available | $3,186 (3) |
| US EPA<br>ELI/JRB<br>1981<br>Calif. | soil | 3,185 cuyd | pesticides | 15 feet | $158/cuyd | $38/cuyd<br>(140 miles) | | $195/cuyd |
| US EPA<br>ELI/JRB<br>1981<br>New Jersey | drums, soil | 5,101 cuyd | solvents<br>metals | 15-26 feet | $37-74/ cuyd | $62/cuyd<br>(440 miles) | $43/ton | $124-171/cuyd |

(1) Landfilled unless otherwise noted

(2) Landfarmed, US EPA subsidized project

(3) State waste category

# TABLE 41

# EXCAVATION EXPENDITURES (continued)

(1982 Dollars

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1) | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1982<br>Wisc. | soil | 100 cuyd | hexavalent chromium | 4 feet | $15/cuyd | $61/cuyd<br>(227 miles) | | $76/ cuyd |
| US EPA<br>ELI/JRB<br>1980<br>Calif. | waste-water | 46,037 cuyd<br>$9.3 \times 10^6$ gal | pesticides class I (3) | pumped from lagoons | $35.75/cuyd<br>(15 miles) | | | $35.75/ cuyd |
| US EPA<br>ELI/LRB<br>1980<br>Calif. | waste-water | 190,950 cuyd;<br>$38.6 \times 10^6$ gal | carbamate fungicide class II-I (3) | pumped from lagoons | $28/cuyd<br>(50 miles) | | | $28/ cuyd |
| US EPA<br>ELI/JRB<br>1980<br>Calif. | waste-water | 268,114 cuyd<br>$54.2 \times 10^6$ gal. | ammonia fertilizer | pumped from lagoons | $4.70-7/cuyd<br>(60 miles) (2) | | | $4.70-7/ cuyd |
| US EPA<br>OERR<br>1982<br>Arizona | liquid | 10,000 gal. | sulfuric acid | leaking tank | $0.70/ gal.<br>$141/cuyd<br>vacuum truck | $2.56/mile/ truckload | $0.40/gal<br>$80/cuyd<br>landfill | $17,000<br>(1) |

(1) Landfilled unless otherwise noted; Total includes other tasks (2) Landfarmed, USEPA subsidized project
(3) State waste category

## TABLE 42
## EXCAVATION COST ESTIMATES

**(1982 Dollars)**

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1 | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA JRB-RAM<br>1980 | sediments | 10 cuyd | not given | not given | $1.77/cuyd | $94.40/cuyd<br>(200 miles) | $283.20/ cuyd | $379.37/ cuyd |
| SCS<br>"impound."<br>1980 | soil,<br>sludge | 4,368 (2) cuyd | "hazardous" | not given | $0.85-1.27/ cuyd<br>$44.84- 67.26 | $1.67-4.39/ ton<br>(20 miles) | $214.17/ ton | $216.69- 219.23/ ton<br>(2) |
| SCS<br>"landfill"<br>1980 | soil | 780,000 cuyd | "hazardous" | not given | $3.42- 4.09/cuyd | $5.27-11.96 cuyd<br>(20 miles) | $214.17/ ton | $222.87- 230.23/ ton |
| US EPA CH2MHill 1983<br>New Jersey | topsoil<br>fill | 100 cuyd<br>51,876 cuyd | none;<br>solvents, Hg, Be | not given | $2.49/cuyd<br>$1.18/cuyd | not given | not given | -- |

(1) Landfilled

(2) SCS assumes one cuyd = 1.89 tons

## TABLE 42
## EXCAVATION COST ESTIMATES (continued)

### (1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1 | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA/ NJ DEP Dames & Moore 1982 N.J. | soil, sediment | not available | solvents | not available | not available | $17.50/ton<br>.32/ton/mi.<br>(55 miles) | $12-20/ cuyd;<br>sanitary landfill | --- |
| US EPA/ NJ DEP Dames& Moore 1982 N.Jersey | soil, sediment | not available | solvents | not available | not available | $17.50/ton<br>(100 miles) | $30-50/ ton/mi.<br>interme-diate landfill | --- |
| US EPA/ NJ DEP Dames & Moore 1982 | soil, sediment | not available | solvents | not available | not available | $70/ton<br>(400 miles) | $60-80/ cuyd<br>engineered landfill | --- |
| US EPA SCS 1983 | not given | not given | not given | not given | not given | $52-76<br>$0.13-19/ cuyd (2)<br>(see text) | not given | --- |

(2) Assumption: 20 tons/truckload, 400 miles

Muddy conditions at the Missouri Case Study site caused some delays in excavation work. The pails at the US EPA, OERR cleanup in Florida, were in a canal. Technicians in full level A protective gear had to retrieve them by boat.

Health and safety requirements and costs were rarely documented and hence, their actual effects on costs are not accurately quantifiable. Since the relative effects of these requirements are potentially greater for excavation/removal than from other technologies, their approximate effect warrants brief recapitulation here.
Given the following level of personal protection:

1. Level A - requires full encapsulation and protection from any body contact or exposure to materials (i.e., toxic by inhalation and skin absorption).
2. Level B - requires self-contained breathing apparatus (SCBA), and cutaneous or percutaneous exposure to unprotected areas of the body (i.e., neck and back of head) be within acceptable exposure standards (i.e., below harmful concentrations).
3. Level C - hazardous constituents known; protection required for low level concentrations in air; exposure of unprotected body areas (i.e., head, face, and neck) is not harmful.
4. Level D - no identified hazard present, but conditions are monitored and minimal safety equipment is available.
5. No hazard - standard base construction costs.

Source: "Interim Standard Operating Safety Guides," EPA 1982

The following levels of productivity have been assumed for other estimates:

| Site Level | Productivity | Equipment |
|---|---|---|
| A | 10% - 15% | 50% |
| B | 25% - 50% | 60% |
| C | 25% - 50% | 75% |
| D | 50% - 70% | - - |
| E | 70% - 100% | - - |

Source: CH$_2$ M Hill, Inc.

This effect on productivity is already reflected in the expenditure data, but inadequate technical data was available to detail the protection levels for each site.

The loading costs for liquids were lower than for solid, and were generally too low to be significant. But costs of solidification or incineration may have negated the savings. Liquid wastes at the New York City #1 and California #2 Case Study sites were quickly and continuously pumped into trucks or trains instead of by the bucket load as with contaminated soil and sludge. Drum handling was most efficiently performed with a hydraulic drum grappler at the Case Study Massachussetts #1 and New Jersey sites. This backhoe attachment rented for over $200/day, but use of it reduced labor costs and other equipment charges by speeding up the loading process. The net effect on cost is unclear from the available case study data, but the use of this apparatus by experienced removal contractors suggests an economizing value.

Waste quantity probably affected excavation costs through unquantifiable economies of scale. Larger sites such as the Maryland and California #1 Case Study sites could maximize the use of backhoes because of the greater amount of waste present and thus reduce the cost-per-unit removed. However, this effect does not appear to be significant since waste quantity and unit excavation cost among the case study sites does not appear to be related.

Transportation -

The distance between the removal and disposal sites is generally the most significant factor affecting transportation costs. Since the costs for transportation of PCB waste did not appear to vary significantly from non-PCB RCRA waste, transportation costs for both waste types are listed together in Table 43. The average cost for the twelve sites for which separate transportation costs were available was $0.17/ton/mile (SD = $0.04/ton/mile).

## TABLE 43
## TRANSPORTATION EXPENDITURES

| Data Source (1) | Unit Weight Cost (divided by) | Distance | = = | Unit Distance Cost |
|---|---|---|---|---|
| ELI/JRB-Massachussetts #1 | $135/ton | 513 miles | | $0.26/ton/mile |
| ELI/JRB-New Jersey | $ 57/ton | 440 miles | | $0.13/ton/mile |
| ELI/JRB-Massachussetts #2 | $ 72/ton | 480 miles | | $0.15/ton/mile |
| ELI/JRB-Missouri | $ 24/ton | 170 miles | | $0.14/ton/mile |
| ELI/JRB-Connecticut | $ 67/ton | 497 miles | | $0.13/ton/mile |
| ELI/JRB-N.Y. City #1 | $ 90/ton | 818 miles | | $0.11/ton/mile |
| ELI/JRB-Minnesota | $ 34/ton | 140 miles | | $0.24/ton/mile |
| ELI/JRB-N.Y. City #1 | $250/ton | 1,740 miles | | $0.14/ton/mile |
| ELI/JRB-N.Y. City #1 | $242/ton | 1,420 miles | | $0.17/ton/mile |
| ELI/JRB-N.Y. City #2 | $ 94/ton | 400 miles | | $0.19/ton/mile |
| EPA,OERR-Florida | $ 68/ton | 400 miles (2) | | $0.10/ton/mile |
| EPA,OERR-Arizona | $ 38/ton | 400 miles (2,3) | | $0.17/ton/mile |

(1) assume 1 cuyd = 1 ton unless specified other wise by contractor or hauler.
(2) assumed; actual distance unknown
(3) 15 cu yd/3,000 gallon truckload assumed

The accessibility of the site to major roads was found to affect costs of transportation at the California Case Study site #1. The contractor stated that a lower price was charged because the site was near a major interstate highway which led to the disposal site. This proximity to the highway minimized the distance travelled on secondary roads and was said to cause less wear and tear on the trucks. This factor may have affected transportation costs at other sites where it was not stated explicitly.

The type of waste material affected transportation costs by dictating the transportation method. Liquid wastes were most economically transported in bulk using truck or train tankers. Solid waste was generally transported via truck, which required extra costs for plastic lining and sealing of tailgate. Sealing of bulk liquid tanks was quicker because it only required closing and checking valves, instead of silicon foam or asphalt sealing necessary on dump truck tailgates. Relative costs of transporting roll off dumpsters was not distinguishable.

The cost of transportation was also affected by the waste quantity, which influenced the type of transportation used. Economies of scale were achieved by using bulk tank trucks and rail cars for large quantitites of liquid waste at sites New York City #1 and California #2 Case Study sites. Rail tankers, which carried several times as much as trucks, provided the lowest unit transportation cost, as shown by the New York City #1 Case Study site. Economies of scale with solids transportation costs were generally limited by state laws regarding weight per axle. Hence, the five axle, 20 cubic yard (15 $m^3$) tractor-trailer dump truck was generally used.

Disposal/treatment -

The most significant factor affecting disposal costs was whether the wastes were PCB contaminated. The disposal of cost for PCB waste was roughly double the disposal cost for non-PCB RCRA hazardous waste. Among the PCB wastes, waste oil with over 500 mg/l PCB at the New York City Case Study Site #1 was disposed of separately from PCB oil with between 50-500 mg/l. The disposal cost alone was the same for waste oil above and below 500 mg/l, but the required separate handling affected other costs because of economies of scale. Liquids from this site were disposed of by incineration, at a slightly higher unit cost than disposal of solids, which were landfilled.

A wide variation in disposal costs for non-PCB RCRA hazardous waste is shown in Table 44. Liquid wastes that were solidified prior to landfilling, such as the ELI/JRB Missouri case study site, cost more per excavated weight because the weight and bulk increased due to the added solidification material such as sawdust or lime. Aqueous wastes such as those at Case Study California site #2 had lower tipping rates than the organic wastes at other sites.

The non-technical factors affecting costs are difficult to quantify fully. An increase in disposal cost was encountered at Case Study Minnessota site when community opposition blocked five initial proposals, which required a more expensive disposal option to be used. Delays and more expensive disposal options were encountered at the Case Study New York City site #1 when an out-of-state landfill refused to accept wastes. The city's consultant stated that this problem "had less to do with waste characterization data discrepancies as with inter-state regulatory political factors" (CH2M HILL, 1982). Pre-1981 costs were significantly lower than the post-1981 costs. This may have been primarily due to the anticipated RCRA landfill regulations, and secondarily to inflation.

### 6.1.4.2 Estimates

The following factors affected the cost estimates for excavation/removal, transportation, transportation and disposal/treatment:

- Excavation:
    - depth
    - method
- Transportation:
    - distance
    - contractor
- Disposal:
    - Method

Generally, the factors affecting estimates (Table 44) were similar to those the affecting the expenditures, which was of significantly less technical detail was available for the estimates scenarios.

# TABLE 44
# PCB EXCAVATION EXPENDITURES

### (1982 Dollars)

| Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal Treatment(1 | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA<br>ELI/JRB 1982<br>N.Y.C. | OIL | 163 tons | PCB (3) | surface tanks | Not Available | $248/ton<br>(1,740 mi.) | $249/ton (2) | $498/ton |
| | pumpable sludge | 240 tons | PCB (3) | surface tanks | Not Available | $240/ton<br>(1,420 mi.) | $233/ton ton (2) | $473/ton |
| US EPA ELI/JRB 1981<br>Mass. | soil sludge | 82 tons | PCB (3) | 3-15 feet | %51/cuyd | $145/ton<br>(513 miles) | $221/ton | $425/ton |
| US EPA ELI/JRB 1980<br>N.Y.C. | flyash/ oil, soil | 2,793 tons | PCB (3) | surface | Not Available | $86/ton<br>(400 mi.) | $226/ton | $313/ton |

(1) Landfilling unless otherwise noted (2) Incineration (3) 50-500 ppm

## TABLE 44

## PCB EXCAVATION EXPENDITURES (continued)

(1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1982<br>N.Y.C | solidified<br>sludge | 7 tons | PCB | surface tanks | not available | $238/ton<br>(400 miles) |  | $238/ton |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |

Excavation -

Excavation cost estimates seemed to reflect primarily varying depths. The SCS "impoundment" estimate and the New Jersey RI/FS assumed that a frontloader would be adequate to scrape up the contaminated soil. The need for a shovel excavator to dig deeper at other sites caused higher estimates. The excavation estimates in all cases were about an order of magnitude lower than the expenditures given above. The reason for this difference may be that excavation of hazardous material does not simply add costs to the estimate for additional tasks such as health and safety protection requirements. Rather it affects all tasks involved in excavation, such as reduced labor productivity due to encumberances from protective gear and delays due to slow turnaround time for chemical analyses. Standard Construction-Engineering manual estimates (see examples Table 45) fail to account for the effect of these factors.

Transportation -

The transportation cost estimates ranged from $1.42 - 94/ton as shown in Table 46. The distance strongly affected the cost of transportation for a ton of waste. The cost-per-ton-per-mile estimates are given in Table 46. They ranged from $0.07 - 0.51/ton/mile. The mean was $0.25/ton/mile (SE=$0.04/ton/mile, n=10), which was almost twice the average expenditures found for transportation. However, the distances assumed for the estimates were significantly lower (3.6 times) than those found to be necessary for actual sites. (Average distance found for transportation expenditures = 618 miles, SD=485 miles; average distance assumption given for transportation estimates = 168 miles, SE=65, n = 7).

## TABLE 45

## ESTIMATES FROM ENGINEERING CONSTRUCTION MANUALS

| Item | Design Basis: | Cost |
|---|---|---|
| Excavation with dragline | 3/4 yd bucket, 90 swing, rating 33 yd/hr | $2.47/cuyd |
| | 1.5 yd bucket, 90 swing, rating 65 yd/hr | $1.76/cuyd |
| Excavation with backhoe | Hydraulic, crawler mounted 1 yd bucket, rating 45 yd/hr | $2.17/cuyd |
| | 1.5 yd bucket, rating 60 yd/hr | $1.96/cuyd |
| | 2 yd bucket, rating 75 yd/hr | $1.93/cuyd |
| | 3.5 yd bucket, rating 150 yd/hr | $1.48/cuyd |
| | Wheel Mounted 0.5 yd bucket, rating 20 yd/hr | $3.95/cuyd |
| | 0.75 yd bucket, rating 30 yd/hr | $2.92/cuyd |
| Excavation with clamshell | 0.5 yd bucket, rating 20 yd/hr | $4.34/cuyd |
| | 1 yd bucket, rating 35 yd/hr | $2.93/cuyd |

Source: Radian, Inc., 1983

## TABLE 46
## TRANSPORTATION COST ESTIMATES

| Data Source | Unit Weight Cost (divided by) | Distance = | Unit Weight Distance Cost |
|---|---|---|---|
| JRB-RAM | $94/ton | 200 miles | $0.47/ton/mile |
| SCS "impoundment" | $1.42-3.27/ton | 20 miles | $0.07-0.19/ton/mile |
| SCS "landfill" | $4.47-10.14/ton | 20 miles | $0.22-0.51/ton/mile |
| New Jersey # 2 RI/FS #2 | $17.50/ton | 35 miles | $0.32/ton/mile |
| New Jersey RI/FS #2 | $17.50/ton | 100 miles | $0.18/ton/mile |
| New Jersey RI/FS #2 | $70/ton | 400 miles | $0.18/ton/mile |
| SCS 1983 | $52-76/ton | 400 miles(1) | $0.13-0.19/ton/mile |

(1) Assumed: 400 miles, see text.

The hauling cost estimates were also found to depend on the type of transporter as shown in Table 47. These specific costs are not necessarily representative but do show a pattern of relative costs.

## TABLE 47

## AVERAGE TRANSPORTATION COSTS BY TYPE OF TRANSPORTER

| Type of Transporter | Unit distance cost/"truckload" | Unit weight distance cost (1) |
|---|---|---|
| Treatment, Storage, and Disposal Facilities Providing Servic to Customers | $2.67/mile<br>($1.66/km) | $0.13/ton/mile<br>($0.09/Mt/km) |
| General Freight Transportation Companies Which May Haul Hazardous Waste on Request | $3.60/mile<br>($2.24/km) | $0.18/ton/mile<br>($0.12/Mt/km) |
| Hazardous Waste Transportation Companies Specializing in Hazardous Waste | $3.70/mile<br>($2.30/km) | $0.19/ton/mile<br>($0.13/Mt/Km) |

Source: SCS Engineers, 1983.
(1) Assume 20 tons (18 Mt)/truckload

## Disposal/Treatment

The most salient factor affecting disposal cost estimates was the method used in the disposal. Cost estimates from the RI/FS from the New Jersey site show a doubling of disposal. Cost for each increase in landfill security. However, since hazardous waste cannot be safely or legally disposed in a sanitary landfill, this cost is inappropriately compared with other estimates for engineered landfills. Also, the other estimates are significantly higher than the actual costs found. Table 48 shows price quotes from a sample of disposal/treatment firms.

### Expenditure Sources

- ELI/JRB Case Studies, 1983
- State and Federal Superfund work

### Estimates Sources

- JRB - RAM, 1980
- Radian, 1983
- US EPA OERR contractor Feasibility Studies
- SCS 1980

Table 48

### AVERAGES OF HAZARDOUS WASTE MANAGEMENT QUOTED PRICES FOR ALL FIRMS IN 1980 AND FOR NINE MAJOR FIRMS IN 1981* (in 1982 Dollars)

| TYPE OF WASTE MANAGEMENT | TYPE OF FORM OF WASTE | UNIT COST | |
|---|---|---|---|
| | | 1980 | 1981 |
| INCINERATION | clean liquids high BTU value | $0.65/gal<br>$131/cuyd | $0.13/gal (1)<br>$26/cuyd |
| | liquids | | $0.59/gal<br>$119.90/cuyd |
| | solids; heavy toxic liquids | $2.12/gal<br>$429.50/cuyd | $2.43/gal<br>$490/cuyd |
| CHEMICAL TREATMENT | acids/ alkalines | $0.21/gal<br>$42.50/cuyd | $0.24/gal<br>$47.50/cuyd |
| | cyanides, heavy metals (2) | $1.30/gal<br>$262/cuyd | $1.76/gal<br>$355/cuyd |
| DEEP WELL INJECTION | oily waste water | $0.13/gal<br>$26/cuyd | |
| | toxic waste water | $0.88/gal<br>$179/cuyd | |
| LANDFILL | Drum | $35.40/55 gal. drum | $45.90/55 gal. drum |
| | Bulk | $53/ton | $67.50/ton |
| LAND TREATMENT | All | $0.07/gal<br>$14/cuyd | |

(1) Some cement kilns and light aggregate manufacturers are now paying for waste

(2) Highly toxic waste

Source: U.S. Environmental Protection Agency. "Review of Activities of Major Firms in the Commercial Hazardous Waste Management Industry: 1981 Update". SW-894.1. May 1982.

## 6.2 HYDRAULIC DREDGING

### 6.2.1 Definition

Hydraulic dredges are used to remove liquid, slurry, or semi-solid (sludge) wastes from waste impoundments, bays, lakes, and channels containing contaminated sediments. Once removed, the wastes can be pumped to treatment and dewatering facilities, or transported to acceptable nearby land disposal sites.

### 6.2.2 Units of Measurement

Costs are given in dollars per cubic yard because it provides a useful standard measurement that is comparable to excavation.

### 6.2.3 Summary Statistics

#### 6.2.3.1 Expenditure

No expenditure data are available at this time.

#### 6.2.3.2 Estimates

The hydraulic dredging cost estimates ranged from:

| | |
|---|---|
| $3.54/yd$^3$ | Contractor dredging only |
| to | |
| $1.25/yd$^3$ | Includes related fixed costs: sheet piling, silt curtain, coffer dam etc. |

The lowest cost estimate includes only contractor prices for the dredging and pumping phases of the operation.

### 6.2.4 Factors Found to Affect Costs

#### 6.2.4.1 Expenditures

No data was available at this time.

#### 6.2.4.2 Estimates

The following factors affected estimates of cost for hydraulic dredging:

- Equipment type
- Pumping system capacity
- Sludge density
- Transportation of slurry
- Related costs

The most important factor affecting costs was the inclusion of related costs. The Feasibility Study for the Illinois site included a variety of necessarily related tasks that are listed in Table 49. These tasks accounted for $119 cu/yd of the total $125/cu/yd unit price (see Table 50). Assuming similar included costs, other site specific factors affect costs. Among these are the type of equipment, which varied with the site. Land based, floating and barge-mounted hydraulic dredges represent increasing costs with increasing depths and waterway sizes. The JRB-RAM and Radian estimates did not specify the dredger type, but the Illinois feasibility study assumed a barge-mounted dredger.

# TABLE 49

## ADDITIONAL RELATED COST ITEMS ESTIMATED FOR HYDRAULIC DREDGING– EPA OERR, $CH_2$ M HILL, ILLINOIS, 1983.

| Task/Cost Item | Quantity | Unit Cost | Total |
|---|---|---|---|
| Pipeline to lagoon | 1,200 LF | \$11.97/LF | \$14,364 |
| Sheet pile caisson - double ring-13400 SF PS 27 | 181 tons | \$23.36/ton | \$422,816 |
| Remove sheet - pile cofferdam | 181 tons | \$11.68/ton | \$211,408 |
| Replace existing piles & floating docks | 690 LF | \$195/LF | \$134,550 |
| New boat hoisting facility | 1LS | \$15,000 | \$15,000 |
| Sediment control - 2 x silt curtain | 600 LF | \$ 95/LF | \$ 57,000<br>\$855,138 |

\$855,138/7,200 cuyd = \$119/cuyd related costs + hydraulic dredging (\$6.12/cuyd) = \$125/cuyd

## TABLE 50
## HYDRAULIC DREDGING COST ESTIMATES

(1982 Dollars)

| Data Source | Quantity/design | Contaminant | Pumping Distance | Cost |
|---|---|---|---|---|
| US EPA<br>JRB-RAM<br>1980 | $694/yd^3/day$<br>suction or cutter head | Not specified | 1,000 ft | $\$3.54 - 5.90/yd^3$ |
| EPA - OERR<br>$CH_2$ M Hill<br>Feasibility Study<br>Illinois | $925/yd^3/day$ | PCB contaminated sludge | 900 ft | $\$6.12/yd^3$<br>(excludes significant fixed and related costs) |
| US EPA<br>Radian<br>1983 | Not specified | Not specified | 1,000 ft | $\$4-8/yd^3$ |
|  |  |  |  |  |

The system capacity likely affected unit costs through economies of scale. Inadequate data were available to confirm this effect.

The sludge density affects unit costs because, after dewatering, low density sludge may yield less contaminated sediment volume than a higher density sludge. This effect must be considered in light of the higher suction rate possible with a lower density sludge.

The different means of transporting the sludge affected costs, since the JRB-RAM and Radian scenarios assumed that only piping would be necessary; whereas the Illinois feasibility study assumed the need for a barge-mounted hopper as well as a pipeline.

Estimated Sources

- JRB-RAM, 1980
- Radian, 1983
- US EPA, OERR contractor Feasibility Studies

## 6.3 MECHANICAL DREDGING

### 6.3.1 Definition

Mechanical dredging with draglines, clam shells, or backhoes is used to remove contaminated sediments from shallow streams, rivers, lakes, and other basins of water. The stream is usually diverted with temporary cofferdams; the sediments are dewatered, excavated, then loaded onto haul vehicles for transport to a disposal site.

### 6.3.2 Units of Measurement

Costs are given in dollars per cubic yard because it provides a useful standard measurement that is comparable to excavation.

### 6.3.3 Summary Statistics

6.3.3.1 Expenditures

No expenditure data are available at this time.

6.3.3.2 Estimates

Mechanical dredging cost estimates ranged from

$1.37
to
4.09/yd$^3$.

The range reflects varying equipment assumptions derived from a single estimate source. The low end involves use of a simple backhoe, while the high end involves use of a clam shell. Mobilization and demobilization costs for the backhoe added $1.50. Hauling and disposal costs of the dredge material was not included (see excavation, transportation and disposal).

### 6.3.4 Factors Found to Affect Costs

#### 6.3.4.1 Expenditures

No expenditure data are available at this time.

#### 6.3.4.2 Estimates

The following factors appeared to affect the cost estimates from mechanical dredging:

- Equipment
    - Use of Barge
    - Excavation method (backhoe, clam shell, or dragline)
- Site condition
    - Depth of sediment
    - Water table

Additional costs: Barge
Sheet piling (pile driver).

Since mechanical dredging is most suited to dredging shallow water, the cost will rise in proportion to the depth of the water and the size of the dredging surface. The use of a barge would double or triple the unit cost for mechanical dredging; hence, the accessibility of the sediments has a significant effect on costs. Also, wet excavation may require sheetpiling or a cofferdam to support the dredging. Table 51 shows the estimated cost for these additional tasks and the pile driver is shown to be significant.

The basic costs of dredging equipment varied with the scenario (see Table 52). Dredging using a hydraulic backhoe (1-3.5 cu/yd bucket) the lowest cost scenario, was \$1.37-2.10/cu/yd. Intermediately, a dredging operation with a 0.75-1.5 cu/yd dragline was estimated at \$1.64-2.43/cu/yd. The highest cost scenario was estimated with a 0.5-1 cu/yd clamshell at \$2.74-4.09/cu/yd.

## TABLE 51

## ADDITIONAL COSTS TO BASIC MECHANICAL DREDGING

| | | |
|---|---|---|
| Barge-mounted dragline or clamshell, hopper dumped, pumped 1000' to shore dump | | $5.31-7.67/yd$^3$ |
| Sheet piling, steel, high strength (55,000 psi); temporary installation (pull and salvage): | 20' deep | $9.72/ft$^2$ |
| | 25' deep | $7.82/ft$^2$ |
| Pile driver; mobilize and demobilize: | 50 mile radius | $ 6,726 total |
| | 100 mile radius | $11,151 total |

**Source:** EPA, Manual for Remedial Actions at Waste Disposal Sites

625/6-82-006

Estimate Source

- JRB-RAM, 1980

# TABLE 52
# MECHANICAL DREDGING COST ESTIMATES

(1982 Dollars)

| Source | Volume | Contaminant | Site Dimension | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB-RAM<br>1980 | 10 $yd^3$ | unspecified | 7.5 feet<br>x<br>30 feet<br>stream bed | \$1.37 - 4.09/$yd^3$ |
| | | | | |
| | | | | |
| | | | | |

## 6.4 DRUM REMOVAL, TRANSPORTATION AND DISPOSAL/TREATMENT

### 6.4.1 Definition

Drum handling includes excavation in cases where the drums (bucket, pails, containers etc.) were buried and/or staging, overpacking and loading for transport. Transportation involves hauling loaded material to an off-site disposal or treatment facility. Disposal/treatment may include landfilling and/or other technologies such as neutralization, solidification or treatment. These are combined here because the cost for all three tasks are often combined into a unit price.

### 6.4.2 Units of Measurement

Costs are usually given in terms of dollars per drum (bucket, pail, containers, etc.) for comparison purposes. However, these costs may include other component tasks such as overpacking and handling adjacent contaminated soil, as noted.

### 6.4.3 Summary Statistics

6.4.3.1 Expenditures

The following ranges of expenditures were found from drum removal, transportation and disposal/treatment:

Drum removal: $60-1,168/drum
Transportation: $15-261/drum (30-480 miles)
Disposal/treatment: $36-360/drum

These cost elements cannot necessarily be summed, since the extremes of the ranges are derived from different sources with different scenarios and assumptions.

Site Total: $60-1,528/drum

Some of the costs for the above three tasks may have been combined in the new data. The high expenditures for the removal costs, may reflect the use of overpacking and containerization. Transportation cost of a drum likely varied with distance, but distance information was rarely available. Some of the disposal costs given also include disposal of contaminated soil. Operation and maintenance costs may include groundwater monitoring and, possibly, site inspections or security to prevent future illegal dumping, which is often repeated at former sites. These costs were accounted for separately, when they were encountered.

#### 6.4.3.2 Estimates

No handling cost estimates data are available at this time.

### 6.4.4 Factors Found to Affect Costs

#### 6.4.4.1 Expenditures

The following factors were found to affect drum removal expenditures given in Table 53 in the Raw Data section.

| | |
|---|---|
| Removal - | Waste type |
| | Drum condition |
| | Drum size |
| | Drum situation, depth |
| | Adjacent soil contaminant |
| | Demurrage |
| | Economies of scale |
| Transportation - | Distance |
| Disposal - | Waste type |

## TABLE 53
## DRUM HANDLING EXPENDITURES

(1982 Dollars)

| Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Tans. (Distance) | Disposal/ Treatment | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA OERR Date unknown<br>Phila. | solid | 0.6 cuyd. | caustic soda | surface | $400/drum<br>$1,468/ cuyd (2,4) | $230/drum | $75/drum | $1,410 (1) |
| US EPA OERR Date unknown<br>Calif. #1 | liquid | one 55 gal. drum | unidentified | surface | $686/drum (5) | not available | | $686/ drum |
| RI DEM<br>US EPA<br>1981<br>Rhode Island | drums<br>soil | 4,500<br>unknown | solvents | average 20 feet<br>(3-35 feet) | $363/ drum | $ 106/drum | | $469/ drum |
| US EPA OERR Date unknown<br>Florida | one, 30 gal. pail | 0.15 cuyd | Calcium- | surface | $129/drum | $10.20/mile | $300/drum | $453<br>(1) |

(1)Total cost may include other tasks
(2)Overpacking

(3) 50-500 ppm; minor component
(4) drum = 0.27 cuyd
(5) cost may include transportation and disposal

## TABLE 53

## DRUM HANDLING EXPENDITURES (continued)

(1982 Dollars)

| Data Source | Material | Quantity | Contaminant | Excavation Depth | Excavation /Removal | Trans. (Distance) | Disposal/ Treatment(1) | Total |
|---|---|---|---|---|---|---|---|---|
| US EPA<br>OERR 1982<br>Florida | liquid;<br>5 gal. pails | 16.7 cuyd;<br>757 pails | Ca oxide<br>chlorinated lime | surface | $460/cuyd | $0.17/cuyd/mi<br>(2 tucks)<br>$68/cuyd (4) | $356/cuyd | $18,155 (2,4)<br>$24/pail<br>($884/cuyd) |
| ELI/JRB<br>1981<br>New Jersey | drums, soil | 5,101 cuyd | solvents<br>metals | 15-20 feet | $34-69/ cuyd | $57/cuyd<br>(440 miles) | $40/ton | |
| ELI/JRB<br>Conn. 1978 | drums<br>soil | 4,770 cuyd | solvents<br>metals | 3-13 feet | $11/cuyd | $67/ton<br>(494 mi.) | $40/ton | $119/ton |
| ELI/JRB<br>Massach. 1978 | drums | 481 cuyd (3) | solvents | surface | Not Available | $71/cuyd<br>(480 miles) | $84/ton | -- |

(1) Landfilled unless other wise noted
(2) Total cost may include other tasks
(3) 615 cuyd disposed; cuyd: ton ratio used by contractor = 1:1.3; 276 cuyd aerated on-site
(4) If 400 miles assumed

Removal -

The waste types found at the Michigan, California #2, Florida, Vermont and Philadelphia sites seemed to have had a significant effect on the removal costs. In all cases, the cyanide, caustic soda, ethyl ether (highly flammable), aromatic hydrocarbons and super tropical bleach (calcium oxide-chlorinated lime), required that Level A or B protective gear, treatment (solidification or neutralization) and recontainerization be added to the removal costs. Careful management of these more hazardous wastes generally increased the time necessary for the various elements of the operation such as labor and equipment. Inadequate technical detail was available, however, to quantify its effect.

Poor drum condition increased removal costs because it necessitated overpacking. In cases where waste had leaked out increased costs were incurred for transferring the waste and emptying and crushing the drums. Overpacking 30 and 55 gallon drums required 55 and 80 and gallon overpacks at increased costs.

Most drums were removed from the surface. The removal actions requiring excavation did not cost significantly more than the removals of drums on the surface, suggesting that the added costs of backhoes and drum grapplers were less significant than other items of cost such as treatment or protective gear necessary for hazardous waste. Also, a drum of an unidentified liquid floating in a Los Angeles, California river required additional expenditures for a boat, but was not significantly more expensive than other surface removal actions.

The extent of soil contamination varied among the sites given. The total cost in some cases included removal of bulk soil, but the unit cost is derived by dividing only this total by the intact or overpacked drums. Hence, the removal cost per drum may be an overestimate in some cases. For the ELI-JRB sites in New Jersey, Connecticut, and Massachusetts, the drums were emptied, crushed and bulked along with contaminated soil necessitating a bulk volume unit cost. More analysis of technical details is necessary to reaggregate these costs.

Based on two observations the economies of scale appeared to affect the unit costs of removal. First, there was a general inverse relationship between the total site costs and the unit cost-per-drum. Second, certain minimum costs were charged for component tasks such as mobilization of technicians and equipment. Mminimum charges also apply to transportation as noted in the discussion of excavation cost factors in the previous section. However, the Michigan site cost for transportation ($2/truck/mile; $60 one truck, 30 miles) was lower than many minimum hauling charges.

Transportation -

Inadequate information was available to compare cost per mile of transportation, but the effect of distance, as well as the rates can be expected to be similar to those found in the above excavation section. Demurrage was not found to significantly affect the costs since it was explicitly charged only at the Philadelphia site ($50 out of $1,410-4%).

Disposal -

The reasons for the widely varying disposal costs were unclear because of inadequate technical detail availability, but they parallel those given in the material removal section.

### 6.4.4.2 Estimates

No cost estimate data are available at this time.

Expenditure Sources

- ELI/JRB Case Studies, 1983
- State and Federal Superfund work

# 7.0 WATER AND SEWER LINE REHABILITATION

## 7.1 SEWER LINE REPLACEMENT

### 7.1 Definition

The process of sewer line replacement, required when damage and/or contamination of piping is extensive, involves the excavation and removal of existing pipework and bedding and replacement with new materials. The remaining trench is then backfilled and compacted to restore the repair site. Preliminary inspection and location of affected sections are considered part of this sewer system rehabilitation method.

### 7.1.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because it provides a simple and standardized measure of sewer lines.

### 7.1.3 Summary Data

7.1.3.1 Expenditures

No actual cost data are available at this time.

7.1.3.2 Estimates

Cost estimates for storm sewer (reinforced conrete) pipe replacement ranged (Table 54) from:

| | |
|---|---|
| $ 55.46/LF | (36 inch diameter) |
| to | |
| $141.60 | (60 inch diameter) |

These estimates included preliminary inspection, trench excavation, pipe placement, backfill and compaction. Allowances for removal of surface pavement and the

### TABLE 54

### SEWER LINE REPLACEMENT COST ESTIMATES

(1982 Dollars)

| Data Source | Design | Pipe Type | Pipe Dia. | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | Inspection, excavation section removal, pipe and bedding replacement backfill and compaction | reinforced concrete | 36 inch | $55.46/LF |
| | | | 42 inch | $68.44/LF |
| | | | 48 inch | $87.32/LF |
| | | | 54 inch | $107.38/LF |
| | | | 60 inch | $141.60/LF |
| US EPA<br>Radian<br>1983 | Inspection, excavation section removal, pipe and bedding replacement, backfill and compaction | reinforced concrete | 36 inch | $53.90/ LF |
| | | | 42 inch | $66.60/ LF |
| | | | 48 inch | $85/LF |
| | | | 54 inch | $104.50/LF |
| | | | 60 inch | $137.90/LF |
| | | | | |
| | | | | |

dewatering of trenches have not been made and may increase costs considerably. Costs of handling and disposal of contaminated soil excavated from sewer-line-replacement sites have not been calculated as they are site specific.

### 7.1.4 Factor Found to Affect Cost

#### 7.1.4.1 Expenditures

No actual cost data available at this time.

#### 7.1.4.2 Estimation

The following factors affected sewer line replacement cost estimates:

- Pipe size
- Pipe composition
- Depth of excavation

Pipe size and depth seemed to be most directly related to the replacement costs for sewer lines. The cost of excavation, which is a major component of replacement, was affected by the depth and size of the pipe. The cost of the new pipe, which is the major material cost factor, was largely a function of the pipe size and composition. Since reinforced concrete pipe was assumed for both estimates, cost estimates vary mostly with size.

Estimates Sources

- JRB-RAM, 1980
- Radian, 1983

## 7.2 SEWER LINE REPAIR

### 7.2.1 Definition

Sewer lines contaminated by migrating leachate may be reconditioned in place if pipe damage is limited. The procedure includes interior inspection, cleaning (mechanical, hydraulic or chemical means) and repair of damaged sections. The upgradient source of contamination is assumed to have been removed or encapsulated for the purpose of this section.

### 7.2.2 Units of Measurement

Costs are given in dollars per linear foot (LF) because it provides a simple and standardized measure of sewer lines.

### 7.2.3 Summary Statistics

#### 7.2.3.1 Expenditures

The only expenditure for cleaning and flushing contaminated sewer lines was:

$15/LF.

The cost per foot for cleaning sewer lines was the same for all piping sizes, which ranged in diameter from 10-21 inches. No cost comparison was possible since only one actual expenditures was available.

#### 7.2.3.2 Estimates

Cost estimates to recondition 12 -inch diameter sewer lines ranged from:

$5.75
to
$15.90/LF

Cost estimates for repair included cleaning, interior inspection and internal grouting for pipe in average condition. Higher estimates were expected for larger diameters and/or more extensive grouting. Disposal costs of removed contaminated material were not included in these estimates.

### 7.2.4 Factors Found to Affect Cost

#### 7.2.4.1 Expenditures

The paucity of data regarding expenditure precludes quantification of component costs and the factors affecting total unit costs (see Table 55).

#### 7.2.4.2 Estimates

The following factors affected cost estimates for sewer line reconditioning (see Table 56):

- Diameter of piping
- Extent of damage

Although the paucity of data hinders quantification of the cost factors, the above two factors appeared to directly affect the level of effort required for repair, and hence, the cost. The extent of the damage was probably the primary factor affecting costs since it was directly related to the amount of repair that was required. The size of the pipe was less directly related to costs, but still affected the area to be repaired. These costs of contaminant handling and disposal were not included in the estimates and must be considered as a site specific factor.

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983

## TABLE 55
## SEWER LINE REPAIR EXPENDITURES

(1982 Dollars)

| Data Source | Design | Total Length | Pipe Dia. | Unit Cost |
|---|---|---|---|---|
| US EPA<br>$CH_2$ M Hill<br>1983<br>New York | Cleaning and Flushing | 29,426 feet | 10 - 21 inches | $15/LF |
| | | | | |
| | | | | |
| | | | | |

## TABLE 56
## SEWER LINE REPAIR COST ESTIMATES

**(1982 Dollars)**

| Data Source | Design | Length | Pipe Dia. | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | Cleaning, T.V. inspection and grout repairs | not specified | 12 inches | \$5.90/LF (1) |
| US EPA<br>Radian<br>1982 | Cleaning,<br>T.V. inspection and grout repairs | not specified | 12 inches | \$5.75/LF (1) |
| | | | | |
| | | | | |

(1) Average Cost; cost will vary with pipe diameter and extent of grouting repairs.

## 7.3 WATER LINE REPAIR

### 7.3.1 Definition

Municipal water lines, contaminated by infiltration of contaminated ground-water or runoff, may be repaired and reconditioned if damage and potential health hazards are limited. After location and inspection of faulty sections, cleaning procedures followed by pipe relining (where necessary) can rehabilitate an effected system. This work may be done in place, without costly excavation.

### 7.3.2 Units of Measurement

Costs are given in dollars-per-linear foot (LF) because if provides a simple and standardized measure of water main lines.

### 7.3.3. Summary Statistics

#### 7.3.3.1 Expenditures

No actual cost data was available at this time

#### 7.3.3.2 Estimates

Cost estimates for water main repair ranged from:

$26/LF 8" diameter
to
$35.50/LF 24" diameter

Restoration of 24 inch diameter concrete pipe was in the same range as smaller diameter iron pipe. Included in the cost-per-linear foot estimate was provision for preliminary T.V. inspection.

### 7.3.4 Factors Found to Affect Costs

#### 7.3.4.1 Expenditure

No actual cost data are available for water main repair.

#### 7.3.4.2 Estimates

The following factors affected cost estimates for water main repair:

- Pipe size
- Extent of damage and contamination
- Accessibility

Pipe size was the primary factor which directly affected the cost estimates for repair (see Table 57). Site specific factors such as accessibility of damaged sections and degree of contamination and damage would directly affect costs, but the cost estimate data were inadequate to quantify these factors.

Estimates Sources

- JRB-RAM, 1980
- Radian, 1983

## TABLE 57
## WATER LINE REPAIR COST ESTIMATES

(1982 Dollars)

| Data Source | Design | Line Type | Pipe Dia. | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | In-Place cleaning, and cement relining of pipes | ductile iron<br>ductile iron<br>concrete | 8 inch<br>12 inch<br>24 inch | $29.50/LF<br>$35.40/LF<br>$29.50/35.40/LF |
| US EPA<br>Radian<br>1983 | In-Place cleaning and cement relining of pipes | ductile iron<br>ductile iron<br>concrete | 8 inch<br>12 inch<br>24 inch | $28.75/LF<br>$34.50/LF<br>$28-34.50/LF |
| | | | | |
| | | | | |

## 7.4 WATER MAIN REPLACEMENT

### 7.4.1 Definition

Water main replacement involves the excavation and removal of extensively damaged and contaminated water pipe sections and bedding, sleeving new sections with polyethelene sheet and relaying them. This is followed by backfilling and compaction of the trench. Preliminary investigation by inspection and analysis is required prior to the replacement procedure.

### 7.4.2 Units of Measurement

Costs are given in dollars-per-linear foot (LF) because it provides a simple and standardize measure of water lines.

### 7.4.3 Summary Statistics

#### 7.4.3.1 Expenditures

No actual cost data are available at this time.

#### 7.4.3.2 Estimates

Water line replacement cost estimates ranged from:

| | |
|---|---|
| $ 58.50/LF | 8" diameter |
| to | |
| $119.18/LF | 24" diameter |

These estimates covered all basic pipe replacement costs including preliminary inspection procedures. Costs were generally proportional to pipe size.

## 7.4.4 Factor Found to Affect Cost

### 7.4.4.1 Expenditures

No actual cost data are available for water line replacement.

### 7.4.4.2 Estimation

The following factors affected water line replacement cost estimates (see Table 58):

- Pipe size
- Depth of excavation

Pipe size and depth seemed to be most directly related to the cost of water line replacement costs. The cost of excavation, which is a major component of water line replacement, was affected by the depth and size of the pipe. The cost of the new pipe, which is the major material cost factor, was largely a function of the pipe size. No significant cost difference between iron and concrete pipe was shown by the limited available data.

Estimates Sources

- JRB - RAM, 1980
- Radian, 1983

## TABLE 58

## WATER LINE REPLACEMENT COST ESTIMATES

### (1982 Dollars)

| Data Source | Design | Material | Size (Dia.) | Unit Cost |
|---|---|---|---|---|
| US EPA<br>JRB - RAM<br>1980 | Inspection, excavation, old line removal, Polyethylene sleeving, pipe laying, backfill, and compaction | Iron<br>Iron<br>Iron<br>Concrete | 8 inch<br>12 inch<br>16 inch<br>24 inch | $60.8/LF<br>$71.98/LF<br>$95.58/LF<br>$119.18/LF |
| US EPA<br>Radian<br>1983 | Inspection, old line removal, Polyethylene sleeving, pipe laying, backfill, and compaction | Iron<br>Iron<br>Iron<br>concrete | 8 inch<br>12 inch<br>16 inch<br>24 inch | $58.50 /LF<br>$70.00/ LF<br>$93.00/ LF<br>$116,00/LF |
| | | | | |
| | | | | |

# 8.0 ALTERNATIVE WATER SUPPLIES

## 8.1 NEW WATER SUPPLY WELLS

### 8.1.1 Definition

New water wells usually involve drilled rather than driven wells, and are typically cased with a PVC sleeve. The costs of providing and operating a pump, and the cost of storage tanks may also be included in the operation. Bottled water from outside sources may also serve a temporary water supply, although cost information on this source is not included in this section.

### 8.1.2 Units of Measurement

Costs are given in dollars per linear foot depth because it provides a standard unit for comparison within the water well industry.

### 8.1.3 Summary Data

#### 8.1.3.1 Expenditures

No expenditure data was available at this time.

#### 8.1.3.2 Estimates

The single cost estimate found for new well installation was:

| | |
|---|---|
| Capital: | $46.25/LF |
| Operation and Maintenance: | $265/year |

The capital cost estimate covers labor, equipment and materials. However, costs for preliminary geologic investigations for well siting were not included. The operation and maintenance figure has been calculated for a well 200 feet deep.

### 8.1.4 Factors Found to Affect Costs:

#### 8.1.4.1 Expenditures

No data was available at this time.

#### 8.1.4.2 Estimates

Due to the limitations of well cost estimation data (see Table 59), no comparison of cost factors can be made. As noted above, however, well depth and diameter as well as hydrogeologic site conditions are general determinants in total costs for well installation.

Estimates Sources

US EPA, OERR contractor Feasibility Studies.

## TABLE 59
## NEW WELL COST ESTIMATES

**(1982 Dollars)**

| Data Source | Design | Depth | Operation & Maintenance | Capital |
|---|---|---|---|---|
| US EPA<br>Radian<br>1973<br>(1978 dollars) | 4 inch diameter<br>pvc casing<br>submersible pump<br>5gpm | 200 feet | $265/year | $46.25/LF<br>($9,250 Total) |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

## 8.2 WATER DISTRIBUTION SYSTEM

### 8.2.1 Definition:

Water distribution systems consist of a network of pressurized pipes connecting individual households with existing water sources, such as mains or reservoirs, and municipal hydrants to a common water source. No source costs for wells or reservoirs are assumed in this section; only connection costs are given.

### 8.2.2 Units of Measurement

Costs are given in dollars per household connected as this is a common factor in the available data and allows an approximation of the numbers of people served by a new water system.

### 8.2.3 Summary Data

#### 8.2.3.1 Expenditures

The range of expenditures was:

$1,091/household
to
$10,714/household

The costs components of the higher expenditure include fire hydrants and all appurtenances; while the lower cost system did not include these costs. Operation and maintenance costs, which may be significant, were not available.

#### 8.2.3.2 Estimates

No estimates data are available at this time.

### 8.2.4 Factors Found to Affect Costs

#### 8.2.4.1 Expenditures

The following factors were found to affect the costs of new water distribution systems (see Table 60):

- Size (pipe length/diameter)
- Inclusion of related costs

The inclusion of related costs was probably the most important factor that affected costs. The more costly system included design work and fire hydrants along all connected streets. The less costly system included only the costs of construction for basic domestic water supply. The two systems shown vary somewhat in size, in terms of both length and diameter. The lower cost Minnesota system connected houses that were closer together than the California system. Also the California system was built to allow for connection of more houses in the future, by using oversized mains that exceeded present system needs. Operation and maintenance costs, which may be significant, are not included. Also excluded is the fee usually charged by a municipality for a connection.

#### 8.2.4.2 Estimates

No estimates data are available at this time.

## TABLE 60
## WATER DISTRIBUTION EXPENDITURES

(1982 Dollars)

| Data Source | Design | Units served | Total Cost | Unit Cost |
|---|---|---|---|---|
| US EPA<br>ELI/JRB<br>1979<br>Minnesota | domestic<br>water distribution system | 11 houses | $12,000 | $1,091/house |
| US EPA<br>ELI/JRB<br>1982<br>California | Includes construction, services, fire hydrants | 28 houses<br>fire hydrant system | $200,000<br>$300,000 | $7,143-10,714/house |
| | | | | |
| | | | | |

## ANNOTATED REFERENCES

CH2M HILL, December 1982. "Draft Engineering Services Report/Quanta Resources Clean-up" Reston, Va. For New York City Department of Environmental Protection. Invoices and daily logs were used to assemble actual removal expenditures.

ELI/JRB Environmental Law Institute, Washington, D.C. and JRB Associates, McLean, Va. Case Studies of Remedial Responses at Hazardous Waste Sites. 1983/85. Invoices, corresponddence, reports and vouchers were used as part of this compilation of 23 case studies around the U.S.

JRB - RAM, 1980. These cost estimates were drawn from the "Manual for Remedial Actions at Hazardous Disposal Sites" Draft final report by JRB Associates, McLean, Va. June 20, 1980. This manual was subsequently published by U.S. EPA as the "Manual for Remedial Actions at Hazardous Wastes Sites." EPA 625/6-82-006. Cincinnati, Ohio, 1982, and again by Noyes Publishing Company, Englewood Cliffs, New Jersey, 1983. The initial draft final report was used because it contained the greatest cost detail. These estimates were drawn principally from construction estimation manuals such as (1) the Means Manual (Godfrey, R.R. (Ed.), 1980, Building Construction Cost Data 1980, 38th Annual Edition, R.S. Means Company, Inc.; (2) Dodge Manual (McMahon, L.; Pereira, P. (Ed.) 1979. 1980 Dodge Guide to Public Works and Heavy Construction Costs. McGraw-Hill Information Systems Co., New York, N.Y.; (3) Richardson Rapid Construction Cost Estimating System (Richardson Engineering Services, 1980); and supplemented with a large number of price quotes drawn directly from industry and commercial sources. Hypothetical site scenarios are given for many of the technologies.

Radian, 1983. These estimates are drawn from the last section of "Evaluating Cost-effectiveness of Remedial Actions at Uncontrolled Hazardous Waste Sites" - Draft Methodology Manual by the Radian Corporation, Austin, Texas, January 10, 1983. These estimates were indexed to constant dollars for March 1982. Many of the estimates were derived from EPA's "Handbook for Remedial Action at Hazardous Waste Sites." EPA 625/6-82-006. Cincinnati, Ohio, 1982. This source was always

supplemented or supplanted by many other estimation sources, including specialized papers for specific technologies, and general construction estimating manuals.

SCS (Engineers), 1980. These cost estimates came from "Costs of Remedial Response Action at Uncontrolled Hazardous Waste Sites" by SCS Engineers, Long Beach California, April 1981. According to this methodology: "For the most part the 1980 Means (Godfrey, R. (Ed.) 1979. Building construction cost data: 1980. Robert Snow Means Company, Inc. Kingston, MA. and Dodge Guides McMahon, L., Pereira, P. (Ed.) 1979. 1980 Dodge Guide to Public Works and Heavy Construction Costs.; McGraw-Hill Information Systems Co. New York, N.Y. were used to obtain the costs needed."

SCS (Engineers), 1981. These cost estimates are derived from Cost Comparison of Treatment and Disposal Alternatives for Hazardous Materials (EPA - 600/52-80-188) published in February 1981 by the US EPA Municipal Environmental Research Laboratory. The estimate compilation was performed by SCS Engineers for a greater Chicago area scenario using the 1978 Means Construction Cost Manual. Hence, mid-1978 costs were originally estimated. For comparison purposes these cost estimates were converted from simple average costs, and the raw data on capital and operation and maintenance costs were used in stead.

US EPA, OERR contractor Bids. Losing bids for Superfund work are used here as estimated costs since they did not serve as the basis for actual construction. However, these estimates reflects a higher level of detail than many other estimates since specific local capabilities are considered. Most of the cost estimates are from 1982 and 1983 estimates.

US EPA, OERR contractor Feasibility Studies. Cost estimates from feasibility studies are generally drawn from non-bid estimates from contractors. Most of these cost estimates are from 1982 and 1983.

US EPA, OERR State and Federal Superfund Work. Records from initial Superfund work, such as bid and change order reports, and spread sheet printouts. All sites are numbered for anonymity, but state locations are given because of its relevance to cost factors such as labor and materials, and site characteristics such as climate.